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Carbohydrate-electrolyte Drink Ingestion and Skill Performance in Tennis

by

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Contents

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ABSTRACT

Aim: To examine the effect of ingesting a carbohydrate-electrolyte drink (CHO-E) compared to a flavoured matched placebo electrolyte drink (PL) on maintenance of skill and performance over 2 hours of indoor tennis match play.

Method: Twenty-two nationally ranked tennis players (15 male, 7 female; mean (SD) height 177 (8) cm, weight 69.2 (9.5) kg) reported to the test centre on four separate occasions, with the first two visits for screening and familiarisation. The final two visits were main trials and participants attended the lab 3 hours post-prandial for baseline nude body mass and blood sample collection. They then performed a standardised warm-up and pre-match skill test, a 2 hour tennis match with ingestion of either CHO-E (Lucozade Sport, GlaxoSmithKline Nutritional Healthcare) or PL beverage administered as a bolus volume (5ml/kg) prior to warm-up, and subsequent volumes (3 ml/kg) every 20 minutes. A final post-match skill test was performed and nude body mass recorded. During the trials, participant's heart rate and movement intensity were monitored, and the match was recorded using a video camera for later match analysis.

Results: There was no difference in environmental conditions or hydration status measures between trials and no difference in skill test scores pre and post-match or between trials at each of these times. Participants on the CHO-E trial had elevated blood glucose concentration throughout the match and also reported feeling more energetic (general activation) and more tense (high activation) one hour into the match compared to baseline, which was not observed in the placebo trial (time x trial interaction $p<0.05$). In addition, accelerometer data showed participants on the CHO-E trial spent more time in moderate intensity activity and less time in low intensity activity than on PL. Match analysis data revealed that ingestion of the CHO-E beverage significantly increased overall percentage of successful serves (mean ± SD = 68 ± 7% for CHO-E compared to 66 ± 7% for PL; $p<0.05$), in particular first serves (65 ± 9% for CHO-E, 61 ± 7% for PL; $p<0.01$) and serves to the advantage side (70 ± 9% for CHO-E, 66 ± 7% for PL; $p<0.05$) over the duration of the whole match. Furthermore, a significant increase in return success rates was observed during the second set of the match ($p<0.05$) on the CHO-E trial. However, performance improvements on the serve and return were found not to be associated with the increase in blood glucose nor player ability.

Conclusions: CHO-E drink ingestion during a tennis match can contribute towards maintaining performance by increasing overall percentage of successful serves and increasing return success rates. These changes may be linked to increased perceived activation, and increased intensity of movement sustained on court. However, the improvements in serve and return success rates are not associated with player ability or glucose elevation, but may reflect a more generic central brain mediated effect of carbohydrate ingestion on skill.

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Chapter 1

INTRODUCTION

The beneficial effects of carbohydrate (CHO) ingestion on endurance exercise capacity and performance have been well documented (Coyle et al., 1983; Davis et al., 1988). Effects of CHO feeding on shorter duration intense exercise has also been studied (Snyder et al., 1993; Bonen et al., 1981; Nicholas et al., 1995; Davis et al., 1997) with positive impacts on delaying the onset of fatigue; however this research has received relatively little attention. Fatigue itself has been demonstrated to negatively influence skill performance during sports which require a high demand on both cognitive and motor skill (Vergauwen et al., 1998a; Burke and Ekblom, 1982; McGregor et al., 1999; Davey et al., 2002). Therefore CHO feeding also may delay the loss of skill that occurs during the later stages of prolonged exercise in sports requiring a high degree of cognitive and motor skill, such as tennis.

Previous studies investigating the effect of CHO ingestion on skill maintenance during game sports have produced mixed findings, with some illustrating no beneficial effect on performance (Zeederberg et al., 1996; Ferrauti et al., 1997; Mitchell et al., 1992), whereas others provide some evidence of maintained skill performance (Vergauwen et al., 1998b; Ostojic and Mazic, 2002; Welsh et al., 2002; Bottoms et al., 2006). However, often the research that has found evidence of maintained skill performance in tennis has induced fatigue through short, high intensity bouts of physical activity rather than real match play situations.

Apart from the somewhat equivocal nature of these results suggesting that future study is warranted, it is also evident that little attention has been paid to shot outcomes and movement intensity in real match situations against an opponent. Thus to further clarify the relationship between CHO ingestion and skill performance in tennis, there is a need to investigate the effect of CHO ingestion on skill maintenance, and physiological and psychological outcomes in tennis players before, during and after prolonged match play.

The aim of this study was therefore to examine the effect of carbohydrate-electrolyte (CHO-E) drink ingestion (Lucozade Sport) compared to a placebo (PL) on maintenance of skill and key measures of performance before, during and after 2 hours of indoor tennis match play in nationally ranked tennis players. We hypothesised that 2 hours of tennis match play would induce fatigue and subsequently a decline in skill, and that ingestion of a CHO-E drink would help to maintain skill and performance compared with ingestion of a non-CHO containing electrolyte beverage.

Chapter 2

REVIEW OF LITERATURE

The aim of this literature review is to examine the research that has preceded this investigation that may relate to a number of different aspects of this thesis. In doing so, it is intended to create a comprehensive overview of past research findings relating to carbohydrate ingestion for tennis, with a particular emphasis on the following topics:

- The physiological demands of tennis
- Metabolite responses to exercise
- Heart rate response to exercise and intensity
- Accelerometry
- Fluid balance
- Carbohydrate ingestion for endurance performance, high intensity exercise, and more specifically tennis
- Measures of arousal and affect
- Measurements of skill and performance
- Match analysis in tennis

2.1. The physiological demands of tennis

Tennis is a sport that has been characterised as having short bouts of intermittent exercise dispersed by longer periods of lower intensity activity (Ferrauti et al., 2003). Early research described the energy demands of tennis as predominantly anaerobic (Richers, 1995); however more recent studies have concluded that competitive tennis players need a balance of both high aerobic capabilities and anaerobic skills (Kovacs, 2007). The mean exercise intensity during a tennis match is about 50-60% of maximal oxygen uptake or 60-80% of maximum heart rate (Fernandez at al., 2006). However mean heart rate values may not be a very accurate reflection of the work endured on a tennis court due to the intermittent nature of the sport and the wide range of heart rate values elicited throughout a match. Phosphocreatine (PCr), which is limited in supply in the body, is therefore the predominant fuel for muscle metabolism during short rallies, along with the anaerobic breakdown of glycogen through anaerobic glycolysis (McCarthy-Davey, 2000).

Five set matches in Grand Slam events have been reported to last an average of 2 hours in duration, however some have lasted longer than 5 hours in total (Hornery et al., 2007b). Research also has found that the actual playing time is only 20-30% of total match duration on clay courts, and 10-15% on fast court surfaces, as average points last only 5-10 seconds (Kovacs, 2007). The numerous rest periods (10-20s, interrupted by several longer periods of 60-90s) in tennis therefore allows the aerobic system to assist in recovery from the high intensity bouts, through the removal and oxidation of glycolytic metabolism by-products, and the restoration of ATP and PCr stores (Mendez-Villanueva et al., 2007a).

On average, players hit the ball 2-3 times during each point, and change direction 4 times per rally (Deutsch et al., 1998). In terms of movement, approximately 80% of all strokes are played within 2.5m of the player's ready position, about 10% are made with 2.5-4.5m of movement, and fewer than 5% of strokes are made with more than 4.5m of movement using a running motion (Ferrauti et al., 2003). Overall, tennis players endure 300-500 high-intensity bouts of effort during a best of three set match; running an average of 3m per shot and a total of 8-12m throughout the duration of a point (Deutsch et al., 1998).

Tennis players require a high degree of skill and training in four main performance areas: physical, physiological, technical and tactical (Kovacs 2007). Physically, players need to develop a combination of speed, power, agility, balance, flexibility, and both muscular and aerobic endurance (Hornery et al., 2007b). In addition, it is vital for players to be mentally tough, confident and at an optimal level of arousal, yet with the ability to remain relaxed and focused throughout matches (Nittinger, 2006). Players also have to react, anticipate and make crucial tactical decisions in only a fraction of a second before every ball that is hit in order to compete on court with intention.

Effects of fatigue on tennis performance

Abbiss & Laursen (2005) defined fatigue as the sensations of tiredness and associated decrements in muscular performance and function. Experiencing fatigue during or following exercise is often a direct result of an athlete reaching one, or a combination of, the following states: the accumulation of metabolic by-products, dehydration, hypoglycaemia, hyperthermia and central disruption (Noakes, 2000). The majority of previous research in the area of fatigue during prolonged exercise has focused on cycling, and has found that the main causes of fatigue are linked to cardiovascular and thermoregulatory failure and/or depletion of endogenous substrate supplies (Armstrong et al., 1985; Coyle et al., 1983; Ivy et al., 1983; Mitchell and Voss, 1991).

The exact causes of muscular fatigue during high-intensity activity, such as tennis, are still to be determined, however it is known that they can originate either centrally and / or in the periphery, and are very complex in nature (Welsh et al., 2002). As match time in tennis increases, intermittent bouts of high intensity activity, repetitive ballistic actions and hot, humid conditions begin to disrupt the homeostatic balance, and ultimately result in the breakdown of several components attributing to performance (Hornery et al., 2007a). It is therefore often possible to observe a decrease in both physical and mental performance that is brought on by fatigue. In this way, performance maintenance depends upon a number of different factors; including the impact of reduced muscular power and endurance, decreased motor skill performance, mental lapses on the nature of the sport, and also the nutritional needs of the athlete (Williams & Nicholas, 1998).

A number of investigations have examined the effects of fatigue on tennis skill and performance (Davey et al., 2002; Davey et al., 2003; McCarthy et al., 1995; Vergauwen et al., 1998a; Vergauwen et al., 1998b). Although the degree of fatigue that players experience during competition is currently unclear, it has been suggested that fatigue may result in a decrease in stroke quality and efficiency (technique), a reduced serve velocity, an increase in the percentage of errors on first serves and defensive groundstrokes, and an increase in errors in successful groundstrokes ("winners") (Davey et al., 2002; Mitchell et al., 1992; Vergauwen et al., 1998a).

McCarthy et al. (1995) examined the influence of fatigue on maximal tennis hitting performance, and found that players performing a skill test, which simulated the metabolic demands of match play, experienced fatigue, which ultimately resulted in a decline of skilled tennis performance. The study involved 18 'elite' tennis players who performed a groundstroke and service skill test before and after an intermittent hitting performance test, which consisted of 4 minutes of maximal hitting against a ball machine. The players were allowed 40 seconds seated recovery in between maximal bouts of hitting, which they repeated until exhaustion. Results showed that mean time to exhaustion was 35.4 ± 4.6 min, and mean hitting accuracy declined by approximately 70% from the start of the performance test to the point of exhaustion, and also from the start of the test to 75% completion. Similarly, Vergauwen et al. (1998b) found reduced serve velocity and accuracy and ground stroke velocity after 2 hours of strenuous training. Vergauwen et al. (1998b) also found that fatigue can lead to a decline in court movement; therefore a player's ability to withstand fatigue may partially influence their competitive success.

Davey et al. (2002) observed a deterioration of ground-stroke accuracy; however after a short rest performance was restored. Interestingly, a tennis skills test, conducted before and after a fatigue intervention, revealed reduced serve accuracy to the advantage court by 30%. In another study, Hornery et al. (2007c) found that serve velocity, ground-stroke velocity, and ground-stoke accuracy all decreased as play time increased. In addition, the acceleration phase of the racket arm on serve decreased with time, which suggests a degree of physiological fatigue.

However, the majority of the studies that have looked at fatigue and tennis have used simulated match play (with a ball machine) rather than a real match situation to induce fatigue. In this way, many of the studies such as Davey et al. (2002) and Vergauwen et al. (1998b) have induced levels of fatigue beyond that normally experienced in a real match situation (e.g. Fernandez at al., 2005; Hornery et al., 2007a; Morante and Brotherhood, 2007; Novas et al., 2003; Smekal et al., 2001), which challenges the application of the findings. It is therefore difficult to draw conclusions on fatigue and tennis with respect to a real match situation, without further examination of performance under real match conditions.

Previous studies investigating either the cause of fatigue or strategies to reduce its influence have also typically focused only on performance outcomes such as stroke velocity and accuracy, and not the biomechanical or psychological changes that may determine such performance outcomes (Hornery et al. 2007c). However, evidence from other sports encourages exploration of the mechanics that underlie skill proficiency or decline (Murray et al., 2001).

Several studies have found that the nature of the task performed largely influences the mechanisms associated with performance impairment (Balsom et al., 1992a; Balsom et al., 1992b). More specifically, the number of movement repetitions, the duration of muscular contraction and the duration of rest periods in between the bouts of high intensity intermittent activity (work to rest ratio) appear to be the key task dependant factors that can influence muscular fatigue (Balsom et al., 1992a; Billaut et al., 2003; Ferrauti et al., 2001b). In addition, motor skills that require higher levels of cognitive demand are more affected by fatigue than skills involving lower levels of cognitive function (Bottoms et al., 2006; Vergauwen et al., 1998b).

Decreased carbohydrate availability has been highlighted as a major cause of fatigue in prolonged activity (Coyle et al., 1983). Although there are a number of important factors contributing to exercise induced fatigue, depletion of muscle glycogen has a major influence during prolonged activity in particular, owing to its limited storage capacity (Kovacs, 2006a). Brun et al. (2001) suggested that working at 55-75% of maximal oxygen uptake would probably lead to a large reduction in glucose and muscle glycogen. As tennis players predominantly compete and practice within this VO_{2max} range, it would seem likely that tennis players are constantly depleting these glucose and glycogen resources, and subsequently suffering from various levels of fatigue. Numerous studies have also concluded that carbohydrate ingestion in a variety of different forms is successful in delaying the onset of fatigue and can improve performance during prolonged exercise (Coyle et al., 1983; Coyle et al., 1986; Coggan & Coyle, 1987; Maughan et al., 1996).

However, owing to the intermittent nature of tennis and the relatively long rest periods between rallies, it is difficult to represent the full demands of the game using mean values. With this in mind, the demands imposed during high-intensity, intermittent activity are probably more relevant to the game of tennis. Using this principle, limitations in energy supply (e.g. phosphocreatine) and intramuscular accumulation of metabolic by-products (e.g. lactate) have often been identified as being the main cause of muscular fatigue during high intensity, intermittent exercise, and evidence suggests that relying on non-oxidative pathways to re-synthesize adenosine triphosphate (ATP) results in impaired muscle force production after relatively few contractions (Mendez-Villanueva et al., 2007a).

Table 1 summarises some of the main findings from previous research on fatigue and tennis performance.

Table 1. Summary of research on the effects of fatigue on tennis performance (Hornery et al., 2007b)

Study	Exercise	Fatigue indices / physiology	Performance measures / skills	Fatigue effects
Dawson et al. (1985)	1hr match vs 1 hr intermittent running in hot, humid conditions (n=8 male) followed by a skill test	- Heart rate - Core body temperature (39ºC) - Body mass loss (2.4%)	- Stroke proficiency - Ground stroke proficiency - Volley proficiency	- ↓ serve accuracy and power - ↓ groundstroke accuracy and power - ↓ volley accuracy and power
Vergauwen et al. (1998b)	Leuven Tennis Performance Test (50 min), a supervised 2-h strenuous training on court, and second LTPT (n=27)	- Shuttle run performance - PRE	- % of errors - Ball velocity - Stroke precision	- ↓ second serve quality and accuracy (7% more errors down the centre) - ↓ serve and groundstroke velocity
Davey et al. (2002) (overnight fast)	A pre- and post- skill test of groundstrokes and service, and the Loughborough Intermittent Tennis Test (LITT) performed to volitional exhaustion (n=18; 9 male, 9 female)	Volitional exhaustion: - Blood lactate - Heart rate (max 190) - RPE (max 20) - Body mass loss (1.5%) - Time to volitional fatigue	- LITT - Loughborough Tennis Skill Test - Ground stroke accuracy (ball machine test) - Serve accuracy (consistency, accuracy, out)	- groundstroke accuracy ↓ by approx. 69% at volitional exhaustion - serve accuracy ↓ by 30% to the right-hand court (pre- vs. post LITT)
Davey et al. (2003) (overnight fast)	92 min 46 s of simulated match play (LITT) Tennis hitting sprint test (n=10; 5 male, 5 female)	Volitional exhaustion: - Heart rate - % body mass loss - Time to volitional fatigue	- Ground stroke accuracy (ball machine test)	- ↓ hitting accuracy by approx. 81% at volitional exhaustion
McCarthy (1997)	Groundstroke and service skill test pre- and post- intermittent maximal hitting performance test of 4 min bouts against ball machine (40s recovery) to exhaustion (n=18)	Volitional exhaustion: - Time to volitional fatigue - Blood lactate	- Ground stroke accuracy - Serve accuracy	- hitting accuracy ↓ - serve accuracy ↓ to the right-hand court

The constraints of field based research in the area of fatigue and tennis present a methodological challenge to investigators, and are possible reasons for the current ambiguous nature of findings. Limitations of previous studies include a restricted measurement approach to the complex skills that determine tennis performance, a lack of sensitivity and large variability in skill or performance measures, the use of non-tennis specific methods to induce fatigue, pre-testing overnight fasting, and fatigue levels that fail to reflect those recorded in real match situations.

Central Fatigue

The specific mechanism behind fatigue is currently unclear, however it has been suggested that central fatigue may play a role (Hornery et al. 2007b). Central fatigue is a phenomenon whereby alterations within the central nervous system (CNS) decrease the ability to voluntarily send a signal to the neuromuscular junction, essentially inhibiting development and / or transfer of the stimulus for muscular contraction (Davis & Bailey, 1997).

Central fatigue has been the focus of several recent reviews (Davis, 1995a; Davis 1995b). During prolonged submaximal and/or exhaustive exercise, branched-chain amino acids (BCAAs) are taken up by the muscle and subsequently plasma concentration decreases. When prolonged or intense exercise causes an increase in the level of circulating free fatty acids (FFAs), it also increases the plasma level of free tryptophan (f-TRP), as FFAs and f-TRP compete for the same binding sites to albumin (Blomstrand et al., 1988). These free fatty acids have a higher affinity for albumin than the loosely bound tryptophan, and will therefore increase the ratio of f-TRP/BCAA in the total plasma concentration (Davis et al. 1992). This increase in the ratio of f-TPR/BCAA will subsequently result in an increase in brain serotonin (5-Hydroxytryptamine [5-HT]) synthesis, which has been associated with central fatigue and a subsequent decrease in performance (Davis et al. 1992; Burke, 2001).

Nutritional supplements have been identified as possibly playing a role in reducing the rise in the level of circulating blood-borne precursors of central fatigue during physical activity (Davis et al. 1992). In particular, carbohydrate supplementation prior to or during such exercise ensures adequate blood glucose and muscle and liver glycogen availability, and could therefore potentially reduce the rise in fatty free acids (Hornery et al., 2007b). However, research into this area has produced mixed findings (Blomstrand et al., 1995; Davis et al., 1992; Davis et al., 1999).

Struder et al. (1995) investigated the effects of 4 hours of continuous tournament-style singles tennis on some of the mechanisms relating to central fatigue, using eight German, nationally ranked male tennis players. The investigators observed reduced plasma BCAA levels and elevated non-esterified fatty acids, which subsequently led to increased levels of f-TRP and an increase in the ratio of f-TRP/BCAA. Struder et al. (1999) also investigated the effects of ingesting carbohydrates prior to and during match play on performance, which was determined by ground stroke accuracy and the number of games won and lost per match. Results showed that ingestion of carbohydrates effectively suppressed the increase of pre-cursors of central fatigue (plasma f-TRP/BCAA and prolactin) in comparison to ingestion of both a placebo and caffeine; however performance remained unaffected in both trials.

Carter et al. (2004) proposed that receptors in the mouth may improve performance by initiating a centrally mediated response to CHO ingestion, as they observed an improvement in performance during a 1-h Cycle Time Trial when using a carbohydrate mouth rinse in comparison to a placebo. However, Beelen et al. (2009) also examined the effect of carbohydrate mouth rinse on exercise performance during a 1-h cycle time trial, and found no difference in performance time, power output, heart rate or RPE between CHO and placebo trials. The discrepancy between findings may be explained by the fact that Carter et al. (2004) tested participants in a fasted state, unlike Beelen et al. (2009).

Liu et al. (2000) used functional MRI scans to examine temporal responses of brain activity in a mid-sagittal section, and observed two peaks in response to glucose ingestion. There was an initial increase in brain activity following oral ingestion, which may have been initiated by the oral receptors in the mouth. The second peak was observed approximately 10 minutes later and was related to increased levels of blood glucose. Similarly, Chambers et al. (2009) found endurance trained cyclists completed a cycling time trial significantly faster when rinsing their mouths with both a 6.4% CHO solution and a 6.4% maltodextrin than with a placebo. In addition, oral exposure to both glucose and maltodextrin was found to activate reward-related regions of the brain.

Chambers et al. (2009) concluded that the improvement in exercise performance observed when carbohydrate is present in the mouth may be due to the activation of brain regions believed to be involved in reward and motor control. In addition, there may be a class of so far unidentified oral receptors in the mouth that respond to the caloric property of carbohydrate independently of those for sweetness.

Overall, it is clear that fatigue is a physiological response to prolonged tennis play that can detrimentally affect performance, regardless of its mechanism. From previous research into fatigue in tennis performance, it appears that the tennis skills investigated are impaired only under extreme forms of physiological stress. However, evidence on the topic of fatigue and tennis is confounding and limited and it is unclear the extent to which players experience fatigue during high-level tennis match play, the exact energy systems used and also the physiological mechanisms are that are likely to contribute the most to performance deterioration. In addition, it is possible that carbohydrate ingestion and/or blood glucose elevation may have a centrally mediated effect, however further investigation is required.

2.2. Metabolite responses to exercise

Blood lactate measurements are often used to estimate intensity of activity, as they provide an indication of the amount of energy produced through glycolytic processes (Bergeron et al., 1991; Mendez-Villanueva et al., 2007b; Smekal et al., 2001; Smekal et al., 2003). Liesen (1983) stated that peak blood lactate concentrations of 7 to 8 mmmol/l have a negative influence on both technical and tactical performance in elite tennis and handball. In the same manner, Green (1979) found that similar high lactate levels correlated with a loss of control and a decline in skill of ice hockey players.

However, a number of studies have concluded that lactate levels remain low (1.53-2.8 mmol/l) throughout tennis practice and match play, and unchanged with carbohydrate ingestion (Bergeron et al., 1991; Fernandez-Fernandez et al., 2007; Fernandez-Fernandez et al., 2008; Ferrauti et al., 2001a; Keul, 1973; Konig et al., 2000; Reilly & Palmer, 1993; Smekal et al., 2001). Bergeron et al. (1991) stated that the moderate intensity and intermittent nature of tennis play reduces the reliance on anaerobic glycolysis for ATP production and provides substantial opportunities for any lactate to be cleared. Similarly, mean blood lactate concentrations of 2.0 ± 0.8 mmol/litre recorded by Fernandez-Fernandez et al. (2007) indicate a that glycolytic energy pathways contribute a low to moderate amount of energy to fuel tennis movements.

Mendez-Villanueva et al. (2007b) found that activity patterns (e.g. rally duration) can influence the physiological demands in men's singles tennis, with higher concentrations of blood lactate being produced in matches with longer rallies and higher number of strokes per rally. Christmass et al. (1998) and Fernandez-Fernandez et al. (2005) found that lengthier or more intense rallies, and serving rather than returning, requires a greater supply of anaerobic energy, with some professional players producing values >8.0 mmol/l during tournament conditions. In the same way, both Reilly and Palmer (1993) and Mendez-Villanueva et al. (2007b) found blood lactate levels to be higher when serving than when returning, and Fernandez-Fernandez et al. (2007) found a significant positive relationship between rally duration, strokes per rally, changes of direction and blood lactate responses in eight junior female tennis players (mean age = 17.3 ± 1.9 years) during actual singles tennis competition.

In contrast, Smekal et al. (2001) and Fernandez-Fernandez et al. (2007) found blood lactate concentrations to be similar during both service and return situations (2.3 ± 0.6 and 2.3 ± 0.9 mmol.litre respectively), which indicates similar glycolytic energy turnover during service and return situations.

Table 6 shows some of the mean values (1.5 - 4.0 mmol/l) for blood lactate concentration obtained in a number of studies during tennis match play.

Table 6. Blood lactate concentrations during tennis match play

Study	**Sex**	**Mean LA ± SD (mmol/l)**	**Surface**
Ferrauti et al. (2001a)	F	1.5 ± 0.7	Clay
Fernandez-Fernandez et al. (2007)	F	2.0 ± 0.8	Hard
Reilly & Palmer (1993)	M	2.0 ± 0.4	Hard
Smekal et al. (2001)	M	2.1 ± 0.9	Clay
Fernandez-Fernandez et al. (2008)	F	2.2 ± 0.9	Clay
Bergeron et al. (1991)	M	2.3 ± 1.2	Hard
Mendez-Villanueva et al. (2007b)	M	3.8 ± 2.0	Clay
Fernandez at al. (2005)	M	4.0 ± 1.1	Clay

A few studies investigating carbohydrate ingestion and tennis performance have found higher levels of blood lactate, however these higher levels have been recorded when the methodology has been based around a skill test. For example, Reid et al. (2008) found blood lactate levels of 4.4-10.6 mmol/l during a tennis skill test. Similarly, Davey et al. (2002) recorded peak RPE scores of 20 ± 0 from as early as 75% into the intermittent test, along with a peak blood lactate concentration of 9.6 ± 0.9 mmol/l recorded 25% into the intermittent test. In comparison, Christmass et al. (1998) recorded peak blood lactate values of 5.9 ± 1.3 mmol/l at the sixth changeover during a singles match. It is therefore important to ensure that testing procedures elicit the right amount of physiological stress on the players so that physiological responses reflect those experienced during a real match, or ideally a real match situation can be used as part of the testing methodology.

However, many factors including individual fitness and time of measurement have been found to affect blood lactate results (Coutts et al., 2003). In addition, Krustrup et al. (2006) stated that blood lactate values do not accurately reflect muscle lactate values during high-intensity intermittent exercise, therefore consideration must be taken when drawing conclusions about blood lactate levels during a tennis match.

Overall, blood lactate levels appear to remain fairly low throughout tennis play; however there are several methodological and analytical limitations that may be influencing the strength of evidence from current research (Cooke & Davey, 2008). Although the literature shows similar lactate concentrations during tennis match play, this should be treated with caution, as numerous factors including individual fitness levels, emotional stress, time of measurement and environmental conditions may affect the results (Fernandez et al., 2006). In addition, sampling times are restricted to natural breaks in a match e.g. change of ends, or disruptions to standard match conditions, therefore the samples only reflect the level of activity during the few minutes before the sample is taken (Bangsbo 1994).

2.3. Heart rate response to exercise intensity

Exercise intensity has been estimated in previous research using measures of heart rate, VO_2, blood lactate concentrations, RPE, and estimates of total energy expenditure (Bergeron et al., 1991; Christmass et al., 1998; Novas et al., 2003). However, these physiological mediators are largely influenced by the physical activity and recovery that a player experiences during a match, which in turn are affected by tactical decisions made by players, the playing situation (serving or returning), the type of playing surface, ball diameter and some environmental factors (Fernandez et al., 2006; Smekal et al., 2001). Overall, the majority of studies have found that tennis players consistently exercise within the range of 55-75% of maximal oxygen uptake or 60-80% of maximum heart rate during a tennis match (Bergeron et al., 1991; Bernardi et al., 1998; Elliott et al., 1985; Fernandez at al., 2006).

Fernandez-Fernandez et al. (2007) assessed certain physiological factors in relation to individual patterns of play in 8 elite junior female tennis players (mean age = 17 ± 2 years) during competition, and found that mean heart rate values (161 ± 5 beats/min) were influenced by the characteristics of the match (rally duration, strokes per rally and changes of direction). Mean heart rate was also found to be significantly higher during service games (166 ± 15 beats/min) than in return games (156 ± 20 beats/min). Results showed the mean number of strokes per rally as 3 ± 2, and climatic conditions during the matches were: air temperature 20 ± 1 ºC and humidity 76 ± 6 %.

Mean heart rates of 140-160 beats / min have been reported to remain relatively stable throughout play in a number of studies (Docherty, 1982; Elliot et al., 1985; Smekal et al., 2001), however Smekal et al. (2001) also found that heart rates can increase above 180 beats / min with more defensive game styles and longer or higher intensity rallies. Similarly, Elliot at al. (1985) reported significantly higher heart rates for the server than the returner, which could be attributed to the more active role of the server or alternatively more psychological stress owing to the need to hold serve. However, Smekal et al. (2001) found no difference in heart rate values were similar when serving and returning.

Morante and Brotherhood (2007) looked at heart rate responses during 43 best of three set matches among 25 players (19 male and 6 female) of both recreational (n=13) and semi-professional / professional coaches (n=12). The mean age of the male players was 24 ± 5 years and the mean female age was 22 ± 2 years. Results showed that heart rate varied widely during play, resulting in a mean response of 136 ± 14 beats / min and no association with air temperature. Similarly, a number of studies have reported mean heart rate values of 140-150 beats/min for a variety of different playing standards of players during tennis match play (Bergeron et al., 1991; Fernandez et al., 2005; Ferrauti et al., 2001a; Hornery et al., 2007a; Kindermann et al., 1981; Novas et al., 2003; 1981; Seliger et al., 1973).

The mean heart rate value of 161 ± 5 beats/min recorded in the Fernandez-Fernandez et al. (2007) study is significantly higher than other studies investigating female tennis players, including Ferrauti et al. (2001a) and Novacs et al. (2003), who found mean heart rate values of 141 ± 18 and 146 ± 20 beats/min respectively. However, this could be due to differences in the exercise protocol used (actual competition compared to simulated match play). Alternatively, the differences in heart rate values may be caused by differences in environmental conditions (Bergeron et al., 1995b; Gonzalez-Alonso et al., 1997) or the variation in age of the participants, as maximal heart rate declines with age (Fitzgerald et al., 1997).

Similarly, the Morante and Brotherhood (2007) study reported a lower mean heart rate value than Fernandez-Fernandez et al. (2007); however this could be due to the significant difference in gender proportions between the two studies. Several studies have found that effective playing time during female singles tennis is higher than during match play in males (Mendez-Villanueva et al., 2007b; Morante and Brotherhood, 2005; O'Donoghue and Ingram, 2001). The mean rally duration value recorded by Fernandez-Fernandez of 8.2s is slightly higher than those previously reported for male tennis players under similar conditions, with values reported in the range of 5.1-7.5s (Deutsch et al., 1998; Fernandez et al., 2006; Mendez-Villanueva et al., 2007b). These values suggest that female tennis players may be typically engaged in longer duration efforts during match play than male tennis players, which may subsequently result in higher mean heart rates.

The average heart rates found by Mitchell et al. (1992) were 135 to 155 beats per minute, which in an endurance activity of the same duration (three hours) would suggest a relatively high rate of energy expenditure. However in tennis these values are not entirely representative of the actual metabolic rate, as the heart rate graphs showed near-maximal peaks followed by troughs below 100 beats / min, and the players' heart rates were below 140 beats / min for approximately one third of the time.

Table 5 provides a summary of average heart rate values (136-161 beats / min) during tennis match play from a number of studies.

Table 5. Summary of average heart rate values during tennis match play

Study	Sex	HR ± SD (beats / min)	Surface
Morante and Brotherhood (2007)	M/F	136 ± 14	Hard
Seliger et al. (1973)	M	143 ± 14	-
Bergeron et al. (1991)	M	144 ± 13	Hard
Reilly & Palmer (1993)	M	144 ± 19	Hard
Kindermann et al (1981)	M	145 ± 20	-
Hornery et al. (2007a)	M	146 ± 19	Clay
Novas et al. (2003)	F	146 ± 20	Hard
Fernandez et al. (2005)	M	147 ± 15	Clay
Smekal et al. (2001)	M	151 ± 19	Clay
Hornery et al. (2007a)	M	152 ± 15	Hard
Fernandez-Fernandez et al. (2007)	F	161 ± 5	Hard

It should be noted that heart rate responses during play can be affected by other factors such as dehydration, thermal stress and psychological stress; therefore these factors should be taken into consideration when heart rate values are used to evaluate intensity during a tennis match (Fernandez et al. 2006).

Rating of Perceived Exertion (RPE)

Rating of Perceived Exertion (RPE) can also be used to estimate intensity levels during exercise. Perceived exertion can be defined as "the subjective intensity of effort, strain, discomfort and / or fatigue that is experienced during physical exercise (Robertson and Noble, 1997)." Rating of Perceived Exertion (RPE) has received growing support as a tool to quantify internal load in other intermittent sports, however there is little evidence of its use in tennis (Foster et al., 1995; Coutts et al., 2003). Novas et al. (2003) reported that RPE can be used to estimate the energy cost of tennis play, with results indicating that competitive match play is typically perceived as “somewhat hard” by elite players (Fernandez-Fernandez at al., 2005; Girard at al., 2006). Similarly, Fernandez-Fernandez et al. (2008) recorded RPE scores for eight tennis players during tournament matchplay, and found an average RPE rating of 12.2 ± 2.4 (range 7-17). However, it should be noted that RPE values can also describe associative thoughts by the participants (e.g. tactical difficulties) in addition to the perception of effort (Baden et al., 2005). It is therefore good practise to use RPE in combination with other methods of measuring exercise intensity, for example heart rate monitors.

Overall, both heart rate and RPE are effective and useful measures of physical activity intensity. Previous research has found that a player’s heart rate in tennis can be affected by a number of different factors, including age, court surface, playing tactics, rally length and recovery duration, however average heart rate values reported during tennis match play were usually in the range of 140-160 beats / min. More future research is required that investigates the impact of nutrition on the different measures of exercise intensity, in particular with regards to tennis.

2.4. Accelerometry

Increasing use of accelerometers to provide ambulatory measures of total body acceleration as an objective measure of physical activity has been seen in recent studies. These measures can be used to estimate the intensity of physical activity over time, which in turn can help to understand the basic characteristics of human movement and to investigate the relationship of physical activity to chronic diseases (Chen and Bassett, 2005; Troiano, 2005). It is therefore important that the devices used to measure physical activity intensity are accurate (Chen and Bassett, 2005).

Numerous studies recently have assessed the validity and reliability of accelerometers in the field. However despite the number of studies, validation standards for accelerometer data reduction have not yet been established (Freedson et al., 1998; Masse et al., 2005). Trost et al. (2005) also stated that no definitive evidence currently exists to indicate that one make and model of accelerometer is more valid and reliable than another. Consequently, Strath et al. (2005) stated that integrating physiological measures, for example accelerometers with heart rate monitors, holds considerable promise to improve measurement precision.

The use of accelerometers in skill sports is not widespread; however the devices are capable of providing information on the intensity and duration of activity, despite having some limitations. Several studies have used accelerometers to monitor the movement or biomechanics of a particular body part in a certain sport, for example running (Wixted et al., 2010). Other studies have looked at the validity and reliability of using an accelerometer to measure velocity, acceleration and movement intensity across a number of sports, including kayaking, walking and running (Dinesh et al., 2010; Janssen & Sachlikidis, 2010).

Montgomery et al. (2010) used accelerometers to help characterise the physical and physiological responses during basketball practice drills and games, in conjunction with heart rate monitors and VO_2. Researchers concluded that accelerometers and predicted oxygen cost from heart rate monitoring systems are useful for differentiating the practice and competition demands of basketball. Similarly, Callaway et al. (2009) compared the use of video- and sensor-based studies of swimming performance (specifically accelerometers), and concluded that multiple sensor-based measurements of swimmers' acceleration profiles have the potential to offer significant advances in coaching technique over the traditional video based approach. In addition, Linamaa (2006) found that the use of accelerometers can help researchers to monitor the performance of ski jumpers. However, to my knowledge no previous research has looked at intensity of movement in sport using an accelerometer and in conjunction with an intervention.

Mean accelerometer outputs and metabolic equivalent (MET) values for tennis have been documented in a study conducted by 277 participants between the ages of 20 and 60 years alongside a number of other sports (Kozey et al., 2010). In addition, Kovacs (2008) discussed the use of an accelerometer to assist tennis coaches who want to objectively measure an athlete's physical performance over time. However, in this article the accelerometer is described as being useful in the areas of rehabilitation from injury, strength monitoring, and assessing tennis players on and off court to see if the players are getting stronger, faster and more powerful. The article does not go into detail about the specific on-court use of accelerometers. To my knowledge, the only other use of accelerometers in tennis to date has been for biomechanical purposes, for example to analyse stroke kinematics, racket vibrations or reaction time (Knudson and Blackwell, 1997; Stroede et al., 1999; Tu et al., 2010); therefore accelerometers have not previously been used to monitor any improvement in movement intensity with the addition of an intervention. It would therefore be useful for further research to investigate the validity and reliability of using accelerometers to measure intensity of movement and footwork on the tennis court.

2.5. Fluid balance

During exercise, thermoregulation is largely accomplished through evaporative heat loss through sweating, as the evaporation of sweat from the skin's surface helps the body to regulate core temperature. If evaporation does not take place then core temperature will rise. Sweating therefore results in a loss of fluid from the body, and if this fluid is not replaced then dehydration will occur. Fluid ingestion during exercise maintains body water for sweat production and increases blood flow to the periphery, therefore maintaining the primary mechanism of heat dissipation in the body (Montain & Coyle, 1992).

A reduction in exercise performance and a decreased work capacity of approximately 30% can occur when an individual is dehydrated by as little as 2% of body mass (Greenleaf, 1992). Research has found that states of hypohydration can lead to compromised cognitive and motor / physical performance (Gopinathan et al., 1988; Devlin et al., 2001). In addition, as the magnitude of hypohydration increases, there is an accompanying increase in core temperature of between 10ºC and 40 ºC for every one percent decrease in body weight (Armstrong et al. 1985).

Dehydration also reduces the rate of gastric emptying, which can subsequently reduce the rate of rehydration from ingested beverages, and can result in feelings of bloatedness, nausea, and general gastric distress (Murray, 1992). Gastric emptying is largely affected by the volume of fluid in the stomach, and increasing the volume will subsequently increase the emptying rate (Maughan & Leiper, 1999). In contrast, gastric emptying is slowed by increasing the carbohydrate content of the solution (Vist &

Maughan, 1995). However, the concentration at which this occurs varies between sources, possibly due to the variety of protocols used.

<u>Sweat rates in sport</u>

Sweat rates have been previously recorded across a wide range of sports, and have displayed a large degree of individual variation. This is not surprising since sweat rates are influenced by a number of different factors including environment, heat acclimation, exercise intensity, hydration status, and level of aerobic fitness (Bergeron et al., 1995a; Kovacs 2006b; Maughan et al., 2004; Morante & Brotherhood, 2007).

Maughan et al. (2005) recorded a mean sweat rate of 1.12 l/h, with a range of 0.71 to 1.77 l/h, in a study sampling 17 professional footballers during a 90-minute training session in a cool (5 ºC) environment. In a warmer environment (24-29 ºC), Maughan et al. (2004) recorded a mean sweat rate of 1.35 ± 0.28 l/h, using the same sweat collection sites during a training session with 24 premiership footballers. Similarly, Shirreffs et al. (2005) sampled 26 footballers during a 90 minute training session in warm conditions (32 ºC), and recorded a mean sweat rate of 1.46 l/h, ranging from 1.12 to 2.09 l/h. Similar to tennis, these studies have found large individual variation between athletes and increased sweat rates when exercising in warmer conditions.

Brown and Winter (1998) recorded a mean sweat rate of 2.37 (1.49-3.25) l/h for male squash players during competition, whilst a mean sweat rate of 0.37 l/h was recorded for both male and female athletes during swimming training (Cox et al., 2002). Sweat rates of 0.98 (0.45-1.49) l/h, 1.39 (0.74-2.34) l/h and 1.6 (1.23-1.97) l/h were recorded for female netball competition in the summer, female rowing training in the summer, and male basketball competition in the summer respectively (Broad et al., 1996; Burke, 2006). However a number of different methods were used across the different studies for collection and analysis of sweat rates, and rates were reported from a mixture of both competitive and training situations. Maughan and Shirreffs (1997) reported that sweat rates of 1.0 to 2.0 l/h are common during most forms of moderate to hard physical activity; however rates of over 2.0 l/h are not uncommon during strenuous exercise or activity in the heat.

Sweat rates in tennis

There are less data on sweat rates in tennis than in many other sports, and the majority of previous research has been carried out in a hot, outdoor environment. Morante & Brotherhood (2007) conducted a study using 86 observations from 43 best of three tie break tennis matches amongst 25 players, with ambient temperatures ranging from 14.5 to 38.4 ºC. Results showed that sweat rates averaged 1.0 ± 0.4 l/h (0.2-2.4 l/h), and a positive relationship was found between sweat rates and air temperature. In contrast, Bergeron et al. (1995b) found mean sweat rates of between 1.71 l/h and 2.40 l/h whilst examining twenty Division I NCAA tennis players who played three matches in three days outdoors in 32 ºC. Lott (2008) recorded mean whole body sweat rates of 0.72 ± 0.26 l/h (range 0.43 to 1.28 l/h) with 16 male university tennis players during one best of three set indoor singles tennis match. Ambient temperature was recorded as 17 ± 2 ºC, and some of the participants in this investigation also took part in this present study.

Bergeron (2003) stated that during a tennis practice or match that can last up to five hours in duration, tennis players' sweat rates are frequently above 1.5 l/h, and it is not uncommon for athletes to have sweat rates greater than 2.5 l/h. This sweat rate may be more than twice the gastric emptying rate of 1.2 l/h for beverages, which subsequently presents a physiological challenge for players (Coyle & Montain, 1992). As a result, a player's metabolic rate has been found to increase substantially during both practise and match play in comparison to resting values (Bergeron et al., 1991), with approximately 80% of this energy is released as heat rather than any physical expense (Bergeron et al, 1995a).

Gender has been identified as having a large influence on fluid loss during tennis play. Bergeron et al. (1995b) found that sweat rates of males were consistently higher than female sweat rates, even when the per-hour sweat rates were expressed relative to estimated body surface area. Male tennis players were also found to have larger overall fluid losses, even though fluid intake was similar. These results are similar to findings from other non-tennis related research (Avellini et al., 1980; Haymes, 1984).

Hornery at al. (2007a) examined 14 male professional tennis players during three international tennis tournaments. Results showed that the players competed whilst experiencing moderate thermoregulatory strain and hypohydration. Hornery at al.

(2007a) stated that the effects of hot and humid ambient temperatures, repeated ballistic actions and intermittent exercise over a prolonged period are predisposing factors to homeostatic disruption and may ultimately lead to impaired performance. In addition, core temperatures approaching hyperthermia levels (exceeding 38.5ºC) were common to both clay and hard court tournaments, regardless of environmental conditions.

MacLaren (1998) suggested that 200mL of fluid every 15 minutes is an adequate rate to maintain body fluid balance during moderate to intense exercise in a warm environment (27ºC). However, this amount is only equal to 0.8 L/hr, which is not even half the amount of fluid that can be lost as a result of sweating (Bergeron et al., 1995a). If ambient temperatures exceed 27 ºC, other researchers have suggested a fluid intake rate of 400mL of fluid every 15 minutes (1.6 L/hr), which is higher than the gastric emptying rate and should therefore limit the amount of body fluid losses during hot and humid conditions (Armstrong et al., 1985; Coyle and Montain, 1992).

Similarly, Mitchell et al. (1992) examined the effect of ingesting a carbohydrate beverage on the fluid balance of twelve competitive tennis players during two, three-hour matches. Results showed that the maintenance of body fluid balance is achieved equally well with either carbohydrate or water solutions, and there is therefore no apparent benefit in including carbohydrates in a fluid-replacement drink during three hours of tennis play to maintain hydration status. In addition, the consumption of 200 ml every 15 minutes prevented severe dehydration and maintained plasma volume without causing extreme fullness under the environmental conditions of 26.65 ºC and 68% humidity.

Pre-exercise hyperhydration has been found to predispose thermoregulatory benefits, including earlier onset of sweating and moderate increases in core temperature (Grucza et al., 1987). Increased core temperature has been associated with increased consumption of muscle energy stores through glycogenolysis (Febbraio et al., 1994) and increased sweat rate in an attempt to dissipate heat through evaporation. In addition, altered CNS function has been proposed as another possible factor contributing to a reduced exercise capacity in the heat (Nielsen & Nybo, 2003). The researchers suggested that increases in core temperature instigate a decrease in neural drive from the CNS, which subsequently causes a reduction in sustained muscle force production.

Horney et al. (2007a) analysed the pre-match hydration status of 14 male professional tennis players during international tennis competition, and found hydration practises of the players to be poor. This coincides with findings from Bergeron et al. (2006) and Dawson et al. (1985), who found that only 27% of the total fluid lost was consumed during play. However, Lott (2008) investigated fluid and electrolyte balance during indoor tennis match play in 16 male university tennis players, and found that players ingested sufficient fluid to replace 89 ± 47% of sweat losses, which was an adequate amount to maintain plasma sodium levels and a sufficient hydration status. Some of the players who participated in this study were also used in this present study.

Overall, The American College of Sports Medicine Guidelines suggest that rehydration strategies should focus on re-establishing pre-exercise body weight levels, which may involve ingesting up to 150-200% of fluid losses because of urine and respiratory water losses. In addition, Maughan and Shirreffs (1997) stated that optimal rehydration can only be achieved if lost electrolytes are replaced along with water.

Electrolyte balance

There is currently some debate as to the best types of fluid to ingest in order to maintain an adequate state of hydration during tennis play. A large number of investigations have shown that a carbohydrate-electrolyte drink promotes fluid absorption better than water (Bergeron et al., 1995a; Murray, 1992), which is important as electrolyte balance helps to limit a player's susceptibility to dehydration, fatigue and possible muscle cramps.

Sodium balance has been found to vary between individuals, and clinical evidence supports the relationship between heat-related muscle cramps, dehydration, and extracellular sodium depletion; caused by either a low dietary sodium intake or individuals sweating an extensive amount of sodium (Bergeron, 2003; Bergeron et al., 1995a). Sodium has also been found to help maintain plasma osmolality and sodium concentration, thereby maintaining the desire to rehydrate (Kovacs, 2006b).

Shirreffs et al. (2006) found that 43 out of 48 footballers lost less than 3 to 4 grams of sodium during a 90 minute training session or match. These measures are not large enough to cause concern, as normal dietary sodium intake should be sufficient to replenish sodium levels. However, the largest individual sodium decrement in the study was 5.1 grams. A sodium loss of such magnitude should be given further attention as this could impair cardiovascular and thermoregulatory function, and may lead to a decrement in performance (Bergeron, 2003; Kovacs, 2006b; Maughan et al., 2004).

With regards to tennis, Bergeron et al. (1995b) found that if tennis matches are played on consecutive days then dietary sodium intake should be increased. However, if matches are played on a one-off basis then normal dietary sodium intake and the ingestion of a carbohydrate-electrolyte drink during the match should be sufficient to maintain plasma sodium levels. Under normal playing conditions, Bergeron et al. (1995a) also found that potassium and magnesium sweat concentrations would not be high.

Lott (2008) investigated fluid and electrolyte balance during an indoor tennis match in 16 University male tennis players. 15 out of the 16 players chose to drink water throughout their match, and these fluid intake choices were found to be adequate to maintain plasma sodium levels. Mean sodium loss was recorded as 1.12 ± 0.45g (range 0.46 – 1.93g). In most instances, dietary and on-court electrolyte intake exceeded electrolyte loss during play by a considerable amount; however there were some large individual variations, therefore for some players there was not a great difference.

Similarly, normal dietary intake should be sufficient to replace any sodium lost during training sessions that are separated by a few days (Maughan et al., 2005). However, if sodium losses over 120 mmol are witnessed then normal dietary sodium intake is unlikely to be sufficient, and such cases a specific electrolyte plan should be constructed.

In summary, normal dietary intake of sodium (2.4g) should be sufficient to replenish sodium levels if training sessions or tennis matches are separated by a few days. If matches or training sessions are played on consecutive days, or if sodium losses through sweat are particularly high for any individual, then dietary sodium intake should be increased. In addition, an electrolyte containing fluid can be consumed to help maintain an adequate electrolyte balance.

2.6. Carbohydrate ingestion

Carbohydrate ingestion for endurance performance

Carbohydrate as a substrate has a number of important uses in the body, including maintaining contraction of skeletal muscle and central nervous system function. Numerous studies have recognised this, and subsequently the beneficial effects of ingesting carbohydrates during submaximal endurance exercise have been well documented (Coyle, 1999; Coyle et al., 1983; Davis et al., 1988). A number of benefits have been identified from these studies in terms of delaying the onset of fatigue, including a reduction in the amount of muscle glycogen depletion, maintenance of blood glucose as an important energy source for both muscle and brain, and / or by altering neurotransmitter activity that could subsequently influence cognition, mood, motivation, and motor skill performance (Davis, 2000). Owing to these benefits, both the American College of Sports Medicine and the National Athletic Trainers Association recommend that athletes in general should consume 3-6 g/h of carbohydrates during exercise (Casa et al., 2000; Convertino et al., 1996).

Carbohydrate ingestion for high intensity exercise

The potential role of carbohydrates on performance sports of intermittent, high intensity has received relatively little attention. A few studies have examined the effects of carbohydrate ingestion on performance during high-intensity bouts of soccer (Leatt & Jacobs, 1989; Zeederberg, 1996) and ice hockey (Simard et al., 1988). Results indicate that carbohydrate ingestion can increase the amount of time athletes can maintain top velocities during an ice hockey game and increase the ratio of goals scored to goals conceded during a soccer match (Simard et al., 1988). In addition, ACSM guidelines recommend carbohydrate supplementation (30-60g/h) for “intense exercise lasting longer than one hour” (Convertino et al., 1996).

Other studies examining high intensity exercise have shown that carbohydrate ingestion can increase the amount of time spent cycling (Davis et al., 1997) or shuttle running (Davis et al., 2000; Davis et al., 1999; Nicholas et al., 1999; Nicholas et al., 1996) when ingested before the onset of fatigue. Leatt and Jacobs (1989) and Nicholas et al. (1999)

also found carbohydrate ingestion to reduce muscle glycogen depletion during a soccer match and after intermittent shuttle running respectively. Coyle et al. (1986) carried out a study with cyclists who were working at an intensity slightly higher than the mean intensity usually experienced during a tennis match (70-75% VO_{2max}), and found that carbohydrate supplementation delayed time to fatigue by 33%.

Welsh et al. (2002) investigated the effect of carbohydrate ingestion on both physical and mental performance during high intensity intermittent activity, using an intermittent high intensity shuttle running protocol designed to mimic the demands of an actual competitive sporting event such as basketball. Welsh et al. (2002) found that carbohydrate ingestion resulted in a 37% increase in run time to fatigue and a faster 20m sprint time during the final 15 minute period. Results indicate that carbohydrates also helped to improve self-reported perceptions of fatigue and whole body motor skill performance during the later stages of exercise. The study concluded that ingestion of carbohydrates appears to improve performance in some, but not all, tasks. In addition, no decreases in performance were observed in tasks that showed no improvement. This would suggest that ingestion of carbohydrates during intermittent high intensity exercise can enhance both physical and mental performance tasks that are prone to decline in response to fatigue.

Another study that investigated the impact of CHO ingestion on perceived feelings during prolonged high-intensity intermittent exercise was that of Backhouse et al. (2007). The perceived activation scale (Felt Arousal Scale [FAS]; Svebak & Murgatroyd) is a six-point, single-item measure of perceived activation / arousal which was used to assess the participants' perception of their own bodily arousal / activation (Backhouse et al., 2007). The Feeling Scale (FS: Hardy & Rejeski, 1989), an 11-point scale ranging from "very good" (+5) to "very bad" (-5), was used as a measure of the affective dimension of pleasure-displeasure. In addition, the 15-point Rating of Perceived Exertion Scale (RPE: Borg, 1998) was used to assess perceived exertion during exercise. Results showed that perceived activation was lower in the placebo trial during the last 30 minutes of exercise. This feeling of lower levels of perceived activation was also accompanied by lower plasma glucose concentrations. In addition, RPE was maintained in the last 30 minutes of exercise during the carbohydrate trial, whereas it carried on increasing in the placebo trial. Therefore, carbohydrate ingestion during prolonged high-intensity exercise appears to positively influence a performer's perception of effort and exertion.

Bottoms et al. (2006) examined the effect of carbohydrate ingestion on skill maintenance in squash, with sixteen male squash players of a high standard. A significantly higher number of balls were observed to hit the scoring zone with carbohydrate ingestion, in particular for the backhand side. This shift towards improved maintenance of skill was also supported by findings of overall faster visual reaction time and a higher blood glucose concentration with carbohydrate ingestion than was observed with the placebo. Similarly, Graydon et al. (1998) assessed the effects of carbohydrate supplementation on shot accuracy and perceived exertion during a conditioned squash match, and found a significant decrement in shot accuracy during the placebo trial in comparison to only a mild reduction in performance during the carbohydrate trial (as measured by pre- and post- shot accuracy tests). In addition, a lower perception of effort was recorded during the carbohydrate trial.

Overall ingestion of carbohydrates during certain types of high intensity exercise appears to elicit some degree of performance enhancement, in particular when a decline in performance is observed without carbohydrate ingestion. However, benefits seem to be more apparent in certain types of sports, for example cycling and shuttle running. This finding may be due to the performance measures used or due to the level of fatigue elicited during the testing. Further research is required across a wider range of high intensity activities using more consistent measures of performance before any accurate conclusions can be made.

Carbohydrate ingestion for tennis

As tennis utilises both the aerobic and anaerobic systems to provide energy, it is likely that tennis players are subjected to different physiological stresses than those experienced during traditional endurance activities. Thus whilst carbohydrate supplementation has been found to be effective in improving performance and postponing the detrimental effects of fatigue in aerobic exercise, there is far more debate and confounding evidence with regards to carbohydrate supplementation and tennis performance. This, however, may be due to the limited number of resources and research studies on this topic.

Carbohydrate supplementation during continuous tennis play has been shown to increase blood glucose levels in tennis players (McCarthy et al., 1995; McCarthy, 1997; Mitchell at al., 1992); however Mitchell et al. (1992) observed no performance benefit with carbohydrate supplementation after three hours of tennis competition. These results were interesting because even though the serve-velocity and shuttle run test results suggested that some fatigue had occurred during the three hours of match play, the ingestion of carbohydrates did not help to prevent a decline in performance. Mitchell et al. (1992) also found no significant differences in the first serve percentage, second serve percentage or unforced error rates between the two trials. Similarly, Ferrauti et al. (1997) found that the overall performance of players (measured by games won and hitting accuracy) did not seem to improve with carbohydrate ingestion during 4 hours of tennis play, even though tennis specific running speed was found to increase. In addition, McCarthy et al., (1995) showed no skilled tennis performance benefits when a carbohydrate solution was ingested during simulated match play.

Owens and Benton (1994) associated the elevated blood glucose concentration from carbohydrate ingestion with faster reaction times, improved mental speed and faster and more efficient information processing levels in comparison with a placebo. Therefore, one could argue that even without enhanced levels of performance, the maintenance of a positive metabolic profile in tennis players may have a positive effect on certain cognitive aspects of a player's game, in particular during long matches.

One of the few tennis specific studies to find an improvement in performance with carbohydrate supplementation was carried out by Vergauwen et al. (1998a), who found that carbohydrate ingestion can improve performance in the later stages of two hours of high level tennis play, by increasing hitting accuracy and stroke quality. Players completed a 'Leuven tennis test' consisting of four games of ten rallies (starting with 1st and 2nd serves) followed by returning between four and seven balls from a ball machine to a random selection of neutral, offensive and tactical situations. The 'Leuven tennis performance test' was then repeated following 2 hours of intensive training. Results showed that players on the placebo trial experienced a greater decline in velocity precision error (VPE), greater error rate on the first service and an increase in the number of errors on defensive balls in comparison with the CHO group. In addition, players performed slower shuttle run times and reached fewer ball machine feeds following the placebo trial. However, this study did not use a real match situation for testing.

Another study to find beneficial effects on tennis performance when ingesting 3ml/kgBM of a 6.9% CHO-E beverage in comparison to a placebo was carried out by McCarthy (1997). During this investigation, blood glucose and lactate concentrations were obtained and skilled tennis performance was observed following simulated match play (92 min 46s) using a ball machine, rather than a training session. Following the simulated match play, players performed a tennis hitting performance test, in which they were asked to aim at targets placed in the rear singles court area, to volitional fatigue. Mean times to volitional fatigue did not differ significantly between the carbohydrate and placebo groups (22.4 ± 8.2 min and 18.5 ± 4.8 min respectively), however hitting accuracy declined in the placebo trial from the start of the performance test to 50% completion and to volitional fatigue, whereas hitting accuracy was maintained in the carbohydrate trial. In addition, blood glucose concentration was maintained at a higher level in the carbohydrate group throughout the simulated match play than with the placebo. In a second part to this study, McCarthy (1997) also found that a high carbohydrate diet (10g/kgBM) helps to maintain hitting consistency and accuracy of the service to the right court as measured using a skill test, in comparison to a placebo group, 22 hours after a prolonged hitting bout. However, no explanation was given for this finding.

Another carbohydrate ingestion tennis study was carried out by Burke and Ekblom (1982), using 2 hours of simulated competitive match play situations whilst ingesting either a carbohydrate beverage (75g/l), water, thermal induced dehydration, no fluids or a control (neutral environment). Performance was measured using ‘total points’ of stroke accuracy on service and groundstrokes, and power output from a vertical jump. Results showed that plasma glucose concentrations increased in the carbohydrate trial by 8.9%, in contrast to a blood glucose decline in all other groups. Total points for the CHO trial were 10.2% higher than in the water trial, and an 11.6% improvement in power was observed with CHO ingestion, in comparison to only 1% in the water trial, therefore skill performance was found to be maintained on the CHO trial. In addition the amount of error was decreased with ingestion of CHO in comparison to water. Burke and Ekblom (1982) concluded that through maintaining a player's hydration status and plasma glucose concentration with a CHO beverage, the quantity of error was minimised and skill was maintained. However, this study only examined five participants and no real matchplay situations were analysed.

Table 2 shows a summary of the findings from previous research on CHO and tennis performance.

Table 2. Summary of findings on Carbohydrates and Tennis Performance

Study	Participants	Length of play	Real match or simulated skill test	Interventions	Performance measures	Performance improvements with CHO?
Mitchell et al. (1992)	12 (10 male, 2 female)	2 x 3 hours	Real match, pre- & post- skill tests	CHO (11.4 ml/kg/h of 7.5%) vs water (PL)	- Serve velocity (but not accuracy!) - 183m shuttle run test	**NO** - Serve velocity & shuttle run tests indicated fatigue but no difference in 1st serve %, 2nd serve % or unforced error rates between CHO & placebo
Ferrauti et al. (1997)	16 (8 male, 8 female)	4 hours	Interrupted tennis: 2 x 75 minute matches, 30 mins rest, 90 min match followed by ball-machine test and tennis-sprint test	CHO (7.6%) vs caffeine vs PL (double blind)	- Ground stroke accuracy (ball machine test) - Games won during match play - Tennis Sprint Test (6 x 15m, 30 sec recovery between each)	**NO** - Performance measured by games won & hitting accuracy during ball machine test did not improve, however tennis specific running speed was found to increase with CHO ingestion
McCarthy et al. (1995)		105 minutes	Simulated match play (3 minute service games)	CHO (2ml/kg BW at 15 min intervals of 6.9%) vs PL	- Serve velocity - Fan drill speed - Percentage points won and lost	**NO** - No performance improvements
Hornery et al. (2007c)	12 (highly trained males)	2 hours 40 minutes	Simulated match play (4 sets) against ball machine	CHO (6%) vs caffeine vs precooling and intermittend cooling vs placebo	- Serve and ground stroke velocity and accuracy - Serve kinematics - Perceptual skill (return of serve test using a computer)	**NO** – CHO conditions resulted in increased blood glucose and reduced pre-exercise thermal strain, however did not affect performance relative to placebo
Struder et al. (1999)	8	4 hours	Interrupted tennis, 3 x 75 minute matches followed by skill test	CHO vs caffeine vs PL	- Ground stroke accuracy (ball machine test) - Games won during match	**NO** – no benefit from ingesting CHO

Study	Participants	Length of play	Real match or simulated skill test	Interventions	Performance measures	Performance improvements with CHO?
Vergauwen et al. (1998a)	13 male	2 hours	Leuven tennis performance test (LTPT), 2 hours strenuous training, followed by another LTPT	CHO (0.7g/kg BM/h) vs CHO & caffeine vs PL (double blind)	- Ground stroke quality (BMT) - Serve quality - 70.5m shuttle run test	**INCREASED HITTING ACCURACY & STROKE QUALITY** – CHO can improve performance in later stages of 2 hours of high level tennis play by increasing hitting accuracy and stroke quality
Burke & Ekblom (1982)	5	2 hours	Simulated tournament tennis	CHO polymer vs water, no fluid control & thermal dehydration	- Ground stroke and service accuracy (ball machine test) - Power output: Sargent Vertical Jump Test	**MAINTENANCE OF GROUND STROKE ACCURACY AND INCREASED POWER BY 11.6%**
McCarthy (1997)	10	92 min 46 secs	Simulated match play using ball machine followed by skill test to volitional fatigue	CHO (3ml/kg BM of 6.9%) vs PL	- Grip strength and endurance - Time to exhaustion - Hitting accuracy	**MAINTENANCE OF HITTING ACCURACY** - Mean time to volitional fatigue did not increase, however hitting accuracy decreased in the placebo trial & was maintained in the CHO trial
McCarthy (1997)	12	T1: 78 min 40s T2: 120 min 40s	Groundstroke and service skill test pre- and post- intermittent maximal hitting performance test of 4 min bouts against ball machine (40s recovery) at 80% HR max ± 5b/m	High CHO diet (10g/kg BM habitual CHO during recovery) vs Control (isocaloric diet of fat and protein)	- Service accuracy - Fan drill sprint test	**INCREASED HITTING CONSISTENCY IN PERFORMANCE TEST AND MAINTAINED ACCURACY OF SERVICE TO THE RIGHT COURT**

Hypoglycaemia

Glycogen storage in the body is small, with approximately 300-400g in the muscle, 80-90g in the liver and circulating blood glucose of 20g (Liebman and Wilkinson, 1994). In prolonged or high intensity exercise, liver glycogen stores deplete and therefore blood glucose concentration may fall below normal levels as active muscles continue to use the available blood glucose. The term hypoglycaemia is used to describe blood glucose levels below 4 mmol/L. An excessive depletion of the body's liver glycogen stores therefore results in decreased substrate availability for energy production and resynthesis of the high-energy substrate adenosine triphosphate (ATP) (Noakes, 2000).

Hypoglycaemia has been found to occur in healthy adults during submaximal, long duration exercise (Coggan & Coyle, 1991), in particular in the heat (Fink et al., 1975). Hypoglycaemia has also been widely recognised to govern a decrement in performance of intermittent or continuous exercise of moderate to prolonged duration by reducing muscle metabolism and neural integration, which controls muscle function (Hawley et al., 1997). Maintenance of liver glycogen stores and a blood glucose concentration above 3.9 mmol/L throughout the duration of any tennis match or practise is therefore important for performance (Bergstrom et al., 1967; McCarthy-Davey, 2000).

However, a number of studies that have investigated the effects of prolonged tennis play at moderate intensity have concluded that hypoglycaemia does not actually manifest during tennis match play (Bergeron et al., 1991; Hornery et al., 2007a; Mitchell et al., 1992). In the study by Hornery et al. (2007a), participants had access to water and carbohydrate loaded (6%) sports drinks during tennis matches, and were permitted to ingest fluid as they desired at change of ends throughout 3 professional tournaments. Results showed that participants had relatively high levels of post-match blood glucose concentrations, similar to that identified in other match play investigations (Bergeron et al., 1991; Burke & Ekblom, 1982; Mitchell et al., 1992), and therefore ingestion of carbohydrate beverages is sufficient to maintain blood glucose concentration to match the increased uptake of glucose by active musculature. Hornery et al. (2007a) concluded that these moderate duration matches may not have been sufficient to challenge and lower blood glucose levels. Further research of prolonged tennis match play, equivalent to five-set matches, is therefore required before hypoglycaemia can be ruled out as a mechanism inducing performance deterioration.

Similarly, Bergeron et al. (1991) found that blood glucose concentrations in tennis players remain stable during play lasting less than 90 minutes, and Mitchell et al. (1992) supported this claim for competition play lasting 180 minutes. Bergeron et al. (1991) also found a non-significant downward "trend" in blood glucose concentration as exercise duration increases, which may result from hepatic glucose production failing to match the increased uptake of glucose by the contracting muscles. Blood glucose is increasingly used to support carbohydrate oxidation as exercise time increases (Bergeron et al., 1991), therefore a longer bout of exercise should theoretically elicit a stronger glucose response. In another study, Burke & Ekblom (1982) measured changes in blood glucose concentration over a two hour simulated tennis match and concluded that blood glucose concentrations would probably fall during prolonged tennis play without appropriate carbohydrate ingestion at frequent intervals.

As many athletes struggle to consume a diet that is sufficient to meet adequate nutritional needs, a number of guidelines have been produced as a guide for carbohydrate consumption. Table 3 outlines a recommended carbohydrate intake for a tennis match.

Table 3. Recommended Carbohydrate intake for a tennis match (Kovacs, 2006a)

	Recommended Intake of Carbohydrates
Before match:	Daily carbohydrate intake for moderate to high intensity training should be 5-7 g/kg (Burke, 2001; Costill & Hargreaves, 1992). If training intensity is increased and during tournaments, carbohydrate consumption should be increased to 7-10 g/kg (Burke, 2001; Costill and Hargreaves, 1992). This should maintain energy stores for performance and also allow for sufficient recovery
During match:	30-60 g per hour of play should be consumed (Casa et al., 2000; Convertino et al., 1996), which is equal to 500-1000 ml per hour of common carbohydrate sports drinks
After match:	Within an hour of exercise, 1.5 g/kg should be consumed (Ivy et al., 1988). This is to assist in liver and muscle glycogen replenishment, and therefore promote adequate recovery

Most commercial sports drinks provide 60-80 g/l of carbohydrates; therefore consuming 500-1000 ml/hr should provide adequate carbohydrates to cover the recommended 30-60 g/hour during the match (Kovacs, 2006a). However, it is important to note that consuming volumes of carbohydrates beyond 60 g/hr does not increase oxidation rates any further, but will actually reduce gastric emptying of fluid into the stomach, which can subsequently lead to gastrointestinal discomfort (Wagenmakers et al., 1993). Bergeron et al. (2006) compared fluid intake and core temperature responses of adolescent tennis players whilst ingesting a carbohydrate electrolyte drink in comparison with water, and found that several players reported feeling some gastrointestinal discomfort following ingestion of the carbohydrate drink.

Mitchell et al. (1989) found that performance improvements during a 12 minute isokinetic time trial following 2 hours of intermittent exercise were similar with ingestion of 34, 39 and 50g of CHO per hour when compared to a water trial. Maughan et al. (1996) also observed an improved endurance capacity by 14% when 16g of glucose was ingested per hour, compared with water. Fielding et al. (1985) found a performance benefit with ingestion of 22g of CHO every hour; however no effects were observed when half this dose was consumed (11g/hr). Similarly, Mitchell et al. (1989) found enhancement of performance during 12 minutes of isokinetic cycling with ingestion of a 12% CHO solution, in comparison to a 6% solution that had no effects on performance. Interestingly, ingestion of an 18% CHO solution did not improve performance. However, all of the aforementioned studies had a fasting period of either overnight or 10 hours prior to testing, which meant the subjects would have started exercising with suboptimal glycogen stores. This fasting is neither realistic nor reflective of a real life situation. In addition, water was often used rather than a placebo, which would have resulted in the participant knowing which test drink they were consuming and subsequently may have influenced results.

Carbohydrates should be ingested during both tennis practice and competition at intervals such that a regular flow of carbohydrates is available from the gut into the bloodstream (Kovacs, 2006a). Coyle (2004) stated that it is inadvisable for players to intake a large amount of carbohydrates early in any practice or match and then refrain from ingesting any more throughout the duration of activity, as this may prepare the body for glucose metabolism and reduce fat oxidation, then subsequently depriving the body of fuel that it has been set up to metabolise. Therefore, as large amounts (>60-90 g/h) or high concentrations (>7-8%) of carbohydrates can cause problems such as gastrointestinal discomfort (Febbraio et al., 1996; Galloway and Maughan, 2000; Wagenmakers et al., 1993); it is advisable to drink small amounts at regular intervals, for example at each changeover in a match (Kovacs, 2006a).

Overall, the contradictory findings in current research regarding carbohydrates and tennis performance may be influenced by a number of differentiating factors; including tennis ability, differences in the type of performance tests used (including match or practice conditions and fasted or non-fasted testing), rest periods, environmental conditions, equipment, and fitness levels of participants. Most performance tests have adopted short duration hitting drills or high intensity tasks designed to replicate physiological stresses experienced on the tennis court. These differ substantially from the controlled time to exhaustion laboratory trials (Coggan & Coyle, 1991; Costill, 1988); mainly due to hormonal (adrenaline) and psychological factors (motivation), the difficulty of simulating tournament conditions in a practice situation, and also the difficulty of accurately measuring "performance" (Kovacs, 2006a).

There is encouraging evidence that carbohydrate supplementation can offset potential manifestations of fatigue through physiological advantages, mainly through adequate maintenance of blood glucose. Numerous guidelines have been produced to help athletes maintain sufficient levels of blood glucose through carbohydrate ingestion; however research has found that ingestion of carbohydrates during a tennis match is sufficient to prevent the manifestation of hypoglycaemia.

2.7. Measures of arousal and affect

Self-reporting indices have commonly been used across all sports to analyse whether or not a participant has felt any psychological improvements as the result of a particular intervention (Backhouse et al., 2007; Jackson et al., 2001; Martin and Gill, 1991). Although evidence about the benefits of ingesting carbohydrates during intermittent high intensity physical activity on physical performance is increasing, there is still little known about its role with regards to mental function.

Carbohydrate ingestion has been found to improve mood states during prolonged training periods in elite cyclists and field hockey players (Backhouse et al., 2005; Keith et al., 1991; Kreider et al., 1995); however results on motor skill performance in tennis players and soccer players have produced mixed findings (Vergauwen et al., 1998a; Zeederberg et al., 1996). Welsh et al. (2002) found that ingestion of a carbohydrate-electrolyte drink during exercise that simulated a competitive game of tennis enhanced self-reported perceptions of fatigue (POMS) during the second half of the protocol in comparison with a placebo. In addition, Keul et al. (1995) found that Davis Cup players reported improved mental alertness and the maintenance of concentration and co-ordination throughout 6.5 hours of matchplay.

A few different methods have been used in an attempt to measure various aspects of mental function. The Activation-Deactivation Adjective Check List (AD ACL) is a multidimensional test to determine a variety of different arousal states, ranging from energetic to tense arousal (Thayer, 1989). Unlike the more conventional adjective checklists comprising three-, five- or seven- point formats; the AD ACL is arranged around a four-point scale and is not completely symmetrical. Its four sub-scales are: Energy (General Activation), Tiredness (Deactivation), Tension (High Activation) and Calmness (General Deactivation). Evidence for its validity can be found in numerous studies that have employed it and obtained consistent findings with established mood and arousal theories (Purcell, 1982; Thayer, 1986;Watson & Tellegen, 1985).

The Feeling Scale (FS) (Hardy & Rejeski, 1989) is a measure of pleasure-displeasure, consisting of an 11 point, single item bipolar scale that can be easily administered during exercise. The scale ranges from +5 to -5. Anchors are provided at zero ('Neutral') and at all odd integers, ranging from 'Very good' (+5) to 'Very bad' (-5). Similarly, the Felt Arousal Scale (FAS) (Svebak & Murgatroyd, 1985) is another subjective scale, however this is a six-point, single-item measure of perceived activation / arousal. The scale ranges from 1 to 6, with anchors at 1 ("low arousal") and 6 ("high arousal"). Both the FS and the FAS can be easily administered during exercise.

Backhouse et al. (2007) investigated the effects of ingesting a carbohydrate (CHO) solution on affective states and rating of perceived exertion (RPE) during prolonged intermittent high-intensity exercise. Seventeen male soccer players completed a prolonged intermittent high-intensity protocol for 90 minutes whilst consuming either a 6.4% CHO or an artificially sweetened PL in a double-blind, counterbalanced design. Affective states were measured using the FS and FAS. Results showed that perceived activation was lower in the placebo trial during the last 30 minutes of exercise compared to the carbohydrate trial, and this was accompanied by lower plasma glucose concentrations. In addition, RPE was maintained in the last 30 minutes of exercise when ingesting CHO however RPE carried on increasing in the placebo trial. Researchers concluded that CHO ingestion during prolonged high-intensity exercise appears to elicit an enhanced perceived activation profile that may impact upon task persistence and performance.

Overall, there are a number of different methods that can be used to effectively measure feelings of arousal and affect. However there is currently relatively little research relating to the beneficial role of carbohydrate ingestion during intermittent high intensity exercise, or specifically tennis, on arousal or affect.

2.8. Measurements of skill and performance

Measures of skill and performance in sport

Measures of skill and performance are some of the most common and important measures used in sports science and physiology, and have been attempted across a wide variety of different sports. A good performance test must have three contributing factors: validity, reliability and sensitivity (Currell and Jeukendrup, 2008). In this respect, skill and performance tests must attempt to simulate as much as possible the performance that is being measured, the inherent variation between trials must be minimal, and tests must be sensitive towards small changes in performance, which could ultimately make the difference between winning and losing in performance sport (Currell and Jeukendrup; Atkinson and Nevill, 2001).

One method commonly used in race-type events such as swimming, running and rowing, is to monitor improvements in time trials or time to exhaustion tests. Time trials provide greater validity than time to exhaustion trials, as they more closely replicate the physiological responses elicited in actual performance racing (Currell and Jeukendrup, 2008). Ball sports and other skill sports that have a scoring system and an opponent, rather than a timed performance such as football, rugby and tennis, are slightly more difficult to simulate and measure in terms of skill and performance. A wide variety of relatively inconsistent methods have therefore been used and subsequently validity may be reduced.

The majority of research into skill sports also has taken place in a practise situation and often certain aspects of performance that are easier to measure have been selected as the chosen performance measure. For example, in football some skills that have been selected as a measure of performance include ball juggling (keeping the ball in the air for as long as possible using the feet), a wall-volley test (getting the ball to hit a target as often as possible in a certain amount of time), and dribbling tests (Reilly et al., 2007). The number of times a ball hits or lands in a certain target area in a given amount of time has also been used to measure performance in a number of other sports, including squash and tennis (Bottoms et al., 2006; Davey et al., 2002; Davey et al., 2003). Ultimately, analysing performance in a practise situation often does not simulate the physiological or psychological demands of a real tennis match very accurately. This failure to replicate these demands can subsequently have implications when drawing conclusions in relation to a real tennis math.

Previous researchers that have used a real match or game situation have most frequently obtained notational analysis as an outcome for descriptive and reporting purposes. Very few ball sport studies have actually used statistical information from real match scenarios with the addition of an intervention, with the aim of investigating any performance benefits from such an intervention. Therefore, further research into skill and performance in sport, which uses a real match situation with the addition of an intervention, is required to more accurately reflect both the physical and mental demands of competitive sport.

<u>Measures of skill and performance in tennis</u>

There are several factors thought to have a negative impact on skill and performance in tennis, including: blood lactate accumulation and muscle damage (McCarthy-Davey, 2000); volitional fatigue (Davey et al., 2002); duration of recovery (Ferrauti et al., 2001b); limited carbohydrate stores (Vergauwen et al., 1998a); high ambient temperatures and hyperthermia (Mendez-Villanueva et al., 2007a); and dehydration (Burke & Ekblom, 1982). Fatiguing exercise has also been found to have a detrimental effect on motor performance and reaction time (Alderman, 1965; Wrisberg & Herbert, 1976). In order to further investigate the mechanisms underlying performance deterioration, it is crucial for skill and performance in tennis to be measured accurately.

Skill tests

The ability to land the tennis ball on a target in the rear of the court has been used to evaluate stroke performance in terms of percentage accuracy or percentage error in a number of studies (Davey et al., 2002; Ferrauti et al., 2001b; Smekal et al., 2000). Tennis ball machine tests have therefore been used in these studies to allow for simultaneous measurement of physiological function and performance in a sport specific manner. However, many ball machine tests are pre-planned, so the participants know where the ball is coming from and going to before the test begins. In addition, high level tennis players are normally able obtain a lot of tactical information from the way any opponent hits the ball. The validity of using a ball machine in relation to a real match play situation is therefore questionable, as it excludes many psychological aspects of the game.

Moreover, to my knowledge all previous research using skill tests has only found carbohydrate ingestion to be effective in maintaining performance in relation to baseline when participants have been pushed to volitional fatigue, or following activity that is physiologically more strenuous than is usually observed under normal match play conditions (e.g. Bergeron et al., 1991; Fernandez et al., 2005; Hornery et al., 2007a). In a number of studies participants also have been fasted prior to testing (Davey et al., 2002; Davey et al., 2003). Methodological oversights therefore challenge the relevance of findings from the majority of previous research into carbohydrate ingestion and tennis performance, owing largely to the fact that the demands of actual match play are extremely difficult to replicate in a scientific field-based experiment that places a large emphasis on control, standardisation and reliability. Unfortunately, data collected under real tournament conditions are currently very limited, and findings have been ambiguous.

Real match situations

A number of studies have used notational analysis from real tennis match play to provide descriptive data (Gillet et al., 2009; Fernandez-Fernandez et al., 2007; Kovacs, 2007; O'Donoghue and Ingram, 2001). However, few studies have used real tennis match play to examine the effect of an intervention. This is possibly due to the nature of testing under tournament conditions, in that it may be obtrusive and distracting to the players involved. Both Ferrauti et al., 1997 and Struder et al., 1999 examined the effect of CHO-E ingestion following a real match play situation, however in both studies performance was measured using a skill test and no performance improvements were found. The only study found to use notational analysis to assess performance with ingestion of CHO-E is Mitchell et al., 1992, and again no performance improvements were identified with CHO-E ingestion. However, the notational analysis was done in real time, both players were ingesting the same solution in any match, and there was also no mention of pre-test diet or physical activity. It is therefore important to increase the amount of future research in tennis using real match play situations rather than a skill test.

2.9. Match analysis in tennis

Tennis is a complex game in which each player has to make hundreds of tactical decisions based upon their own strengths and weaknesses, as well as that of their opponent. A tactical game plan should therefore be constructed prior to any match, taking these strengths and weaknesses into consideration. Players should also take into account the environmental conditions on any match day, including court surface and weather conditions, and be able to adapt their tactics accordingly. Several studies have been carried out that further investigate these tactical decisions, shot outcome and general patterns of play in elite tennis (Gillet et al., 2009; Fernandez-Fernandez et al., 2007; Kovacs, 2007; O'Donoghue and Ingram, 2001).

O'Donoghue and Ingram (2001) carried out notational analysis of singles events at all four Grand Slam tournaments between 1997 and 1999 to determine the effect of court surface and player gender on elite tennis strategy. They found that female tennis players had longer rallies on average than the male players (7.1 ± 2.0 s in comparison with 5.2 ± 1.8 s). In addition, rally length for both male and female players was significantly longer on clay at the French Open (7.7 ± 1.7 s), and shorter on grass at Wimbledon (4.3 ± 1.6 s) than on the hard courts of the Australian and US Opens (6.3 ± 1.8 s and 5.8 ± 1.9 s). This difference in rally length is caused by the ball bouncing lower and faster on a grass than hard court, and higher and slower on a clay court surface. Longer rally length was also found to coincide with a greater proportion of baseline rallies.

O'Donoghue and Ingram (2001) also reported the number of shots per rally, finding that there were approximately 4.6 shots per rally in the men's singles at the Australian Open. This figure is similar to the results from Hughes and Clark (1995), who reported 4.8 shots per rally. The rallies at Wimbledon were again found to be shorter in duration, with Hughes and Clark (1995) and Hughes and Moore (1998) reporting rally lengths of 3.1 and 3.0 shots respectively. However the professional game of tennis has evolved greatly even over the past decade, therefore some more up to date notational information would be useful.

In another study, Kovacs (2007) found that the average duration of a point in tennis can vary greatly depending on a number of factors including playing surface, playing style, environmental conditions, strategy and motivation. Tennis court surfaces can vary in both coefficient of friction and coefficient of restitution, and each of these will subsequently influence the interaction between the tennis ball and the court (Brody, 1987). Courts with a higher coefficient of friction cause the ball to bounce slower, and courts with a higher coefficient of restitution cause a higher ball bounce. Clay courts therefore have both a higher coefficient of restitution and friction than grass or hard courts (O'Donoghue & Ingram, 2001).

In their 2001 study, O'Donoghue and Ingram analysed the time taken by tennis players between and during points. They recorded inter-point times of 18.7 ± 1.9 seconds and 18.3 ± 2.0 seconds, and inter-serve times of 9.3 ± 1.5 and 10.0 ± 1.4 seconds for men's Grand Slam tournament matches played at the Australian Open and US Open (1997-9), respectively. The longest inter-serve time was recorded at Wimbledon (11.0 ± 1.3), which may have been caused by more male players serve-volleying on the faster surface, and subsequently having to walk back to the baseline in between serves. The longest inter-point time for both men and women was recorded at the French Open (18.2 ± 1.6 / 19.5 ± 2.1), which O'Donoghue and Ingram concluded may relate to increased recovery time from the longer duration of rallies on a clay court surface.

Reid et al. (2008) investigated various aspects of tennis performance during a number of tennis drills, and found that players' average movement velocities, and forehand ball speed and accuracy were relatively consistent throughout the testing; however significant declines in forehand shot precision and consistency were observed in the drill that was considered to be the most intensive and most representative of near maximum match play demands. The same drill also elicited higher levels of lactate and forced the players to cover greater distances than the other drills tested.

Several studies have looked at the percentage success rates of first and second serves, and also the outcome of the point. Gillet et al. (2009) reported 62% of all first serves were successful and more than 80% of the serves were returned in the court, when 116 men's singles matches were analysed from the French Open in 2005 and 2006. In addition, 62.1% of all points were won when serving, in comparison to 37.9% when returning, with players winning significantly more points when serving first serves (67.3%) than second serves (46.2%). Receivers were found to have won significantly more points after second serves (46.2%) than first serves (32.7%).

O'Donoghue and Ingram (2001) also reported on the percentage of points won when serving and returning with matches from the Grand Slams between 1997 and 1999. Findings showed that the Men at the French Open won 52% of points when serving and 48% of points when returning (Table 4). These figures indicate a far greater balance between winning points on both the serve and return than in the Gillet study; however the tennis serve has become a lot more powerful even in the eight year period between these two studies, which may account for the differences in results.

Table 4. Percentage of points won from the baseline when serving and receiving (O'Donoghue and Ingram, 2001).

Player	**Sex**	**Tournament**			
		Australian	**French**	**Wimbledon**	**US Open**
Server	Women	46.9 ± 5.8	48.6 ± 5.6	45.7 ± 8.6	47.8 ± 7.1
	Men	48.1 ± 9.7	52.0 ± 8.5	46.6 ± 24.4	47.0 ± 12.2
Receiver	Women	53.1 ± 5.8	51.4 ± 5.6	54.3 ± 8.6	52.2 ± 7.1
	Men	51.9 ± 9.7	48.0 ± 8.5	53.4 ± 24.4	53.0 ± 12.2

Despite a review of published literature identifying a number of investigations that relate to notational analysis, nearly all of the studies found focused primarily on match timings (rally duration, inter-point time and inter-serve time), shorts per rally, shot outcome or influence of court surface on performance. Only a few studies have attempted to make an integrated analysis of physiological and performance analyses.

Hornery et al. (2007a) conducted a study that investigated the relationship between physiological and performance indices of 14 male professional tennis players whilst competing in three international tennis tournaments. Findings revealed that as match duration increased and adverse physiological conditions developed (increased heart rate, body mass deficits and heat strain), elements of both first and second service action were negatively affected. Specifically, consistency in the height of the arm at ball release, and the position and height of the ball toss were the most notable technical inconsistencies. However, while these findings suggest a relationship between physiological strain and diminished technical skill performance, Hornery et al.(2007a) found that modified coordination and timing of the service action did not actually compromise stroke outcome (velocity and accuracy).

In another sport involving similar intermittent high intensity levels to tennis, Royal et al. (2006) found that altered technical competence with increased physiological strain did not affect shooting velocity or accuracy in water polo players. These findings suggest that either technical alterations owing to increased physiological strain are not crucial to maintain stroke velocity and accuracy, or that high level athletes are able to retain performance consistency even when undergoing physiological trauma.

Interestingly, Fernandez-Fernandez et al. (2007) looked at a number of performance variables, including rally duration, strokes per rally and changes of direction, in an attempt to ascertain if the variables had any physiological influence on eight junior female tennis players. The results indicated a significant positive relationship between rally duration, strokes per rally, changes in direction and blood lactate and heart rate responses, with stronger correlations when the players were serving. However, it is unclear whether the physiological changes determined the performance variables or vice versa.

Overall there is a reasonable amount of previous research into notational analysis in high performance tennis, which have produced fairly consistent results in terms of descriptive reporting of tennis shots and timings. However, there are few investigations which have attempted to make a connection between the descriptive performance statistics and physiological outcomes. Further research is therefore required before any conclusions can be drawn on the impact of certain physiological measures on tennis performance.

Chapter 3

METHODOLOGY

Study Participants

A total of twenty-three tennis players (fifteen male and eight female) were recruited for this study, through individual consultation with each participant and through consultation with several National coaches. The inclusion criteria used were to recruit subjects (both male and female) of a National playing standard and between the ages of sixteen and forty. Fifteen of the twenty-three participants were nationally ranked between 5-409 in Great Britain for their age group. Nineteen participants held an LTA rating between 3.1 and 6.2, and competed regularly in tournament play, whilst the remaining four participants played competitively through the University of Stirling Tennis Club Performance Programme, and were rated between 7.1 and 10.2. All participants were training specifically for competitive tennis and were involved in on court and gym sessions typically for around 10-12 hours per week.

The University of Stirling Ethics Committee approved the project. Participants completed a consent form (Appendix 1), and medical history and physical activity questionnaire (Appendix 2) that assessed subject health status prior to entry into the study. If either questionnaire highlighted any potential risks from participation in the study by any subject then that subject was excluded from the study.

<u>Exclusion Criteria included:</u>

1. Those diagnosed with Phenylketonuria (PKU), since an artificial sweetener containing phenylalanine was used in the test food / placebo.
2. Those with known or suspected food intolerances, allergies or hypersensitivity.
3. Women who were known to be pregnant or who are intending to become pregnant over the course of the study.
4. Women who were breast feeding.
5. Participation in another clinical trial.
6. An employee of the sponsor or the study site or members of their immediate family.
7. Anyone taking any other nutritional supplement aimed at improving performance or mental alertness during exercise.
8. Substance abuse (within the last 1 year of alcohol or other substance abuse).

Study Design

The study involved ingestion of either a carbohydrate-electrolyte (CHO-E) drink (active treatment), or a flavour and colour matched electrolyte placebo (PL) drink. The active treatment drink contained 6.4% carbohydrate (Lucozade Sport). The drinks were administered immediately prior to and during a two hour on-court match period. Immediately prior to match play participants ingested 5 ml/kg of the test drink and then 3 ml/kg approximately every twenty minutes (during a normal break in play) up until two hours. This amounted to 1610 ml ingested over two hours for a 70kg participant (containing 103g of carbohydrate).

The products were supplied and labelled by GlaxoSmithKline (GSK) Nutritional Healthcare and were administered by the researcher following a double blind, placebo controlled, cross-over design and were provided in the required body mass adjusted volumes. This study design was chosen to ensure that neither the participant nor the researcher knew what the subject was ingesting during either trial. The randomisation procedure followed a stratified format, with half of the participants receiving active treatment first and half receiving the placebo first during the two main trials. A randomisation schedule was supplied by the Applied Sciences team, GSK Nutritional Healthcare R&D.

Players were asked to attend the University Sports Centre on four separate occasions over a period of three to four weeks for the following procedures: 1. Pre-screening visit; 2. Familiarisation trial; 3. First main trial; 4. Second main trial. For every trial, only one participant was tested at any one time. The other player was only involved in the testing as an opponent for the purpose of the match, therefore the only data that were collected on the opponent were readings of heart rate every 60 seconds using a polar (S625X) heart rate monitor. All main trials were conducted at the same time of day and one week apart. The schedule on each main trial day showing timing of sample collection and measurements made is illustrated below in Figure 1.

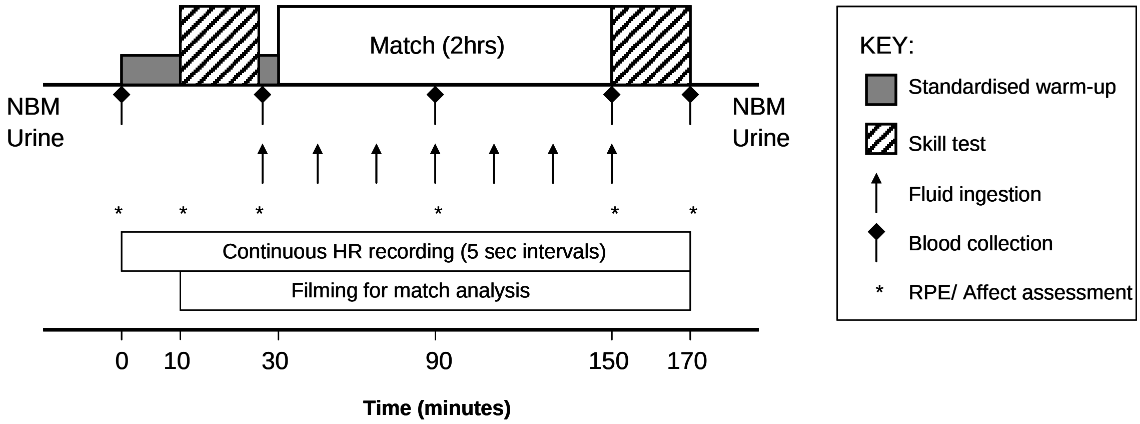


Figure 1: Diagram to show sequence of events during the two main trials. NBM = Nude body mass. HR = Heart rate. RPE = Rating of perceived exertion.

3.1. Pre-screening

The first visit for each participant was to undertake pre-screening tests in the laboratory. Each participant completed both medical history and physical activity questionnaires before taking part, in order to confirm their eligibility for testing. These completed documents were reviewed by a medical practitioner prior to allowing the participant entry into the study. Participants also completed a filming consent form (Appendix 3), and had measurements of height and body mass recorded, before resting heart rate and blood pressure were recorded using a portable semi-automated device (Omron, Bodycare Ltd). Harpenden callipers were used to obtain the sum of 4 skinfolds, based on measurements taken according to the ISAK protocols (Norton and Olds, 2000), and participants were fitted with a Polar (S625X) heart rate monitor.

Following the skinfold measurements, participants had to complete a graded maximal treadmill test to exhaustion to determine their maximal heart rate (HR_{max}) response to exercise. The test was performed on a Marquette 2000 treadmill, and participants began the test at an incline of 0% and a speed of 8-10 km/hr, depending on estimated individual fitness levels. Fitness levels were estimated based on knowledge of the participants and their performance in previous group fitness sessions. For the first six minutes, the treadmill increased speed by 1 km/hr every 2 minutes at a constant incline, thereafter the treadmill remained at a constant speed but increased by 2% incline every

1 minute, until the participant reached volitional exhaustion. Heart rate was recorded every 2 minutes for the first 6 minutes, and every minute thereafter. On reaching volitional exhaustion, the participants were instructed to straddle the running belt, maximal heart rate was recorded, and speed and incline levels were reduced to 3.5 km/hr and 0% respectively for the participant to walk for recovery.

Participants' General Practitioners were not notified of their involvement in the study unless any unusual or surprising observations were made on any of the data obtained.

3.2. Familiarisation trial

On the second visit to the Sports Centre, participants had to undertake a familiarisation trial to ensure that the players had experience of all procedures prior to entering the two main trials. During this visit they were taken through all of the pre-testing procedures for the main trials (see below); including pre-test lab measurements, a dynamic warm-up, five minute racket warm-up, pre-match skill test, 5 minute match warm-up, and one competitive set of tennis against an opponent. Water was ingested for the familiarisation trial, rather than the sports drink as used for the two main trials; however volume consumed was representative of the main trials. Participants consumed 5 ml/kg of their body mass following the initial baseline skill test, and then 3 ml/kg every twenty minutes during the set.

3.3. Main trial protocol and data collection

During the final two visits to the Sports Centre, participants took part in the two main experimental trials, which were undertaken one week apart and at the same time of day. Dietary intake and physical activity were recorded in diary format in the three days preceding the first main trial, and replicated in the three days preceding the second main trial. The participants were able to eat their normal diet in the days preceding the trials but were asked to replicate this diet before each main trial and were also asked to avoid ingestion of caffeine on the morning of each main trial.

Pre-test laboratory data collection:

Participants were asked to attend the laboratory two hours following ingestion of a standardised breakfast (cereal with milk, a glass of orange juice, and toast with jam). On arrival at the laboratory, participants were asked to empty their bladder in order for a urine volume to be recorded and a sample was stored for later analysis. Nude body mass (NBM) was measured using a set of Ohaus, CS2000, Fischer Scientific precision balance scales, and resting heart rate and blood pressure were recorded using a portable machine. A baseline capillary sample was collected, prepared and stored in an ice bath for the duration of the trial, prior to being frozen for later analysis (see below). This was taken from either the second, third or fourth finger of the non-dominant tennis hand, and was varied throughout the trial. Each participant bathed the hand in a basin of warm water to improve peripheral circulation prior to collection of the baseline sample (at time 0 min). The finger was then dried with paper towel, wiped clean with an alcohol wipe, dried again with a tissue, and then blood was drawn using an 'Accu-Check Soft Clix-pro' sampling pen. The first drop of blood drawn was wiped away with a clean tissue to avoid interference from skin cells or debris, and then 20µl of blood was collected in a capillary tube and dispensed into 200µl of ice cold 0.3N perchloric acid (PCA). Samples were then shaken vigorously before being placed in the ice bath for storage until the end of the trial.

Participants were fitted with a Polar (S625X) heart rate monitor on their chest and heart rate watch on their wrist, as well as an Actigraph accelerometer (Actigraph USA) which was worn on the side of the right hip. Finally, participants were asked to rate how they were feeling and their level of arousal. This was done using a feeling-displeasure scale (Appendix 4; Hardy and Rejeski, 1989) from -5 ("very bad") to +5 ("very good"), an arousal scale (Appendix 4; Svebak & Murgatroyd, 1985) from 1 ("low arousal / activation") to 6 ("high arousal / activation"), and an Activation-Deactivation Adjective Check List (AD ACL) (Appendix 5; Thayer, 1989), which is a multidimensional test of various states of arousal. Participants were then transferred to the tennis court.

<u>On-court data collection:</u>

On arrival at the tennis court, the participant's opponent was fitted with a heart rate monitor (Polar S625X), to record the intensity of the opponents play throughout the duration of the two main trials. The temperature and humidity of the tennis court were recorded using a digital barometer (Cranlea), and both players were then taken through a standardised dynamic warm-up lasting approximately 10 minutes, followed by a 5 minute groundstroke warm-up (appendix 6). On completion of the warm-up, the participants were again asked to rate how they were feeling and also their level of arousal using the three scales as previously described, in addition to their Rating of Perceived Exertion (RPE, Appendix 7; Borg, 1998) of the warm-up.

Following the warm-up, the participants completed a pre-match skill test lasting approximately 20 minutes (see below). Immediately following the skill test, a further capillary blood sample was collected, along with further responses to feeling, arousal and RPE. The participants were provided with a 5 ml/kg of their body mass volume of the test drink (either the placebo electrolyte drink (PL) or the carbohydrate / electrolyte drink (CHO-E)), as measured on a set of electronic Ohaus scales.

Both the participant and the opponent went on to perform a standardised match warm-up, including groundstrokes, vollies and serves, lasting five minutes. The players then completed two hours of match play using Tretorn tennis balls, during which the participants ingested 3 ml/kg of the test drink every 20 min (or at the nearest time to this during a normal change of ends). A match time of two hours was selected based on previous research indicating that five set matches in Grand Slam events last an average of two hours in duration (Hornery et al., 2007b).

All participants had been carefully paired with an opponent of a similar standard and all matches adhered to the rules set by the International Tennis Federation (www.itftennis.com). During the match, heart rate of both players was recorded every five seconds using Polar Heart Rate monitors. Players were required to collect their own balls throughout the duration of the two hour match. In addition, participants were permitted to wear only shorts and a t-shirt for the two main trials.

Following one hour of play and at the end of the two hour match, another capillary sample was collected, and Rating of Perceived Exertion (RPE; Borg, 1998) and affect (Hardy & Rejeski, 1989; Thayer, 1989) were again recorded. New balls were also provided following one hour of match play. After two hours of match play, the participants repeated the skill test. Immediately following the second skill test, a final blood sample was collected, along with final measures of RPE and affect. The participants then returned to the laboratory to provide a final urine sample and nude body mass, to complete the testing for that day. The consumption of all beverages was strictly prohibited in both the two hour period preceding the trial, and between ingestion of the final test drink and final weigh in.

Following the completion of each main trial, the pre- and post- urine samples were labelled and stored in the refrigerator for later analysis. In addition, the five capillary blood samples were spun at 5,000 rpm for ten minutes at 4ºC, labelled and frozen for later glucose and lactate analysis, once all testing was completed.

Skill test protocol

For the skill test, the participants were assessed on the accuracy and consistency of groundstrokes, and the accuracy, consistency and speed of serve in an unopposed playing situation. After a standardised dynamic warm-up and 5 minute groundstroke warm-up, participants undertook a groundstroke skill test in which they performed 22 alternate cross-court and down-the-line forehand drives, aiming at a target ($3m^2$) placed in the back corner of the court (Figure 2), using Treton Micro X tennis balls. The test was replicated on the backhand side; playing alternate cross-court and down-the-line backhand drives. The whole groundstroke test was then repeated again, so that the participants played 88 balls in total; 44 balls on the forehand side and 44 on the backhand.

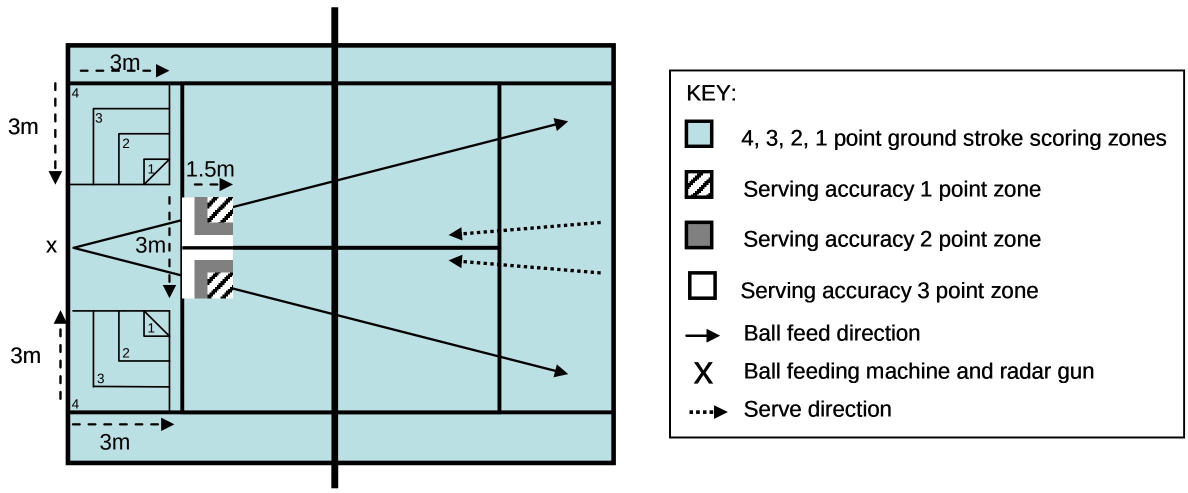


Figure 2: Skill test zones for accuracy and consistency of groundstrokes and serve. Modified version of that reported by Davey et al (2002).

The tennis balls were delivered to the player using a Lobster ball feeding machine set at a firing speed of 60 mph, at 6 second intervals and 3 degrees elevation, to mimic the ball speed and frequency of hitting normally encountered during match play. Normal hitting frequency was established by setting the ball machine to fire the ball simultaneously as the participants' ball crossed the baseline where the ball machine was situated. This frequency would subsequently mimic an opponent returning the participants' shots. The ball machine had to be set to fire the balls with no spin, so as to keep the ball speed up and also help to preserve the balls. The outcome of each forehand or backhand was assessed for accuracy and consistency, and recorded using a 4 point scoring zone (Figure 2). The outcome of the first 2 balls from each set of 22 was not recorded, to allow both the ball machine and the player to settle into a rhythm.

Participants then performed a 2 minute standard match service warm-up, before completing a serving skill test involving 10 first serves to the deuce service box, 10 first serves to the advantage service box, and 10 second serves to the each service box (40 serves in total). The participant was aiming to land the ball within a target area ($1.5m^2$) at the distal end of the service box and down the centre of the court. Again, the accuracy and consistency (from scoring areas 1, 2 and 3) were recorded as in the groundstroke test. Speed of service (km/h) was also recorded using a Sports Radar Model 3600 speed gun that was positioned behind the ball machine, in the centre of the court.

<u>Match analysis</u>

During the on-court testing the participants were recorded using a camera positioned above and to the rear of the court to capture all court activity. Using notational analysis on the output from the camera system, we were be able to obtain the following parameters: first service and second service type (centre line, body or out wide); outcome of serve (ace, winner, fault, or still in play); return of serve shot type and outcome; number of rallies; number of shots in the rally and rally outcome; forced and unforced error rates. The accelerometer attached to the right hip of each participant was used to monitor the intensity of the participants' movement and combined with heart rate data provided useful information on sustained intensity of play during the match.

<u>Urine analysis</u>

Volume of pre- and post- match urine samples were individually determined using a measuring cylinder. The total volume was recorded to allow for correction of body mass change to calculate sweat loss and a sample of urine was retained for measurement of urine electrolyte losses.

Urine osmolality (freezing pont depression method, Roebling) and urine electrolyte analysis (ion selective electrode analysis, EML105, Radiometer) were used to track changes in hydration status and electrolyte loss between trials.

Estimation of sweat loss

For the purpose of this study, any fluid lost through respiratory or substrate exchange has been disregarded when calculating sweat loss from pre- and post- nude body mass values, as the volumes are likely to be small (Maughan et al., 2004; Shirreffs et al., 2005). All calculations regarding fluid loss are therefore based solely on fluid intake and body mass change, corrected for urine formation. This calculation is consistent with previous research by Shirreffs et al. (2005).

Blood analysis

Blood glucose was analysed using the glucose oxidase method (Spectrohpotometric method, ABX diagnostics), and blood lactate was analysed fluorimetrically using the method of Maughan (1982).

Heart rate data

All heart rate data were downloaded directly from the heart rate monitors of both participants and opponents to the computer following each main trial.

Statistical analyses

Primary outcomes (skill test scores, subjective measures of performance including affect, RPE, and blood and urine parameters) were first analysed for baseline score differences using analysis of variance (ANOVA), and then between baseline and following 2 hours of the set-play match using a repeated measures analysis of variance (RMANOVA) with post-hoc Tukey tests with time and trial as the main within group factors. Match analysis was compared between placebo and active treatment trials using paired T-tests and RMANOVA where appropriate. A correlation analysis was performed to determine whether any associations were observed between change in skill performance and blood glucose elevation (pre-drink to peak concentration) and player ability based on coach ranking. All analysis were performed using Minitab v.15 and significance was accepted at $P<0.05$. The results from any dropouts from the study were excluded from overall analysis. All values are reported as mean ± SEM.

Chapter 4

RESULTS

Characteristics of Study Participants

The mean age, height, body mass, maximum heart rate (HR_{max}), and sum of 4 skinfold thickness for the participants were as follows. Males: age = 22.2 ± 6.7 years; height = 180.1 ± 6.2 cm; body mass = 72.1 ± 8.3 kg; HR_{max} = 191 ± 6 beats/min; sum 4 skinfolds = 36.4 ± 15.1 mm. Females: age = 20.9 ± 7.0 years; height = 170.3 ± 4.9 cm; body mass = 63.4 kg ± 6.7 kg; HR_{max} = 188 ± 10 beats/min; sum 4 skinfolds = 55.5 ± 12.7 mm.

Study Outcome Variables

Twenty two players completed the study. The 23rd participant vomited during the final skill test of the final trial; therefore the results from that participant were excluded from the analyses (on completion of the study this was discovered to be on a placebo trial).

Each match was played indoors on a hard court surface under controlled ambient conditions. Participants were asked during which main trial they thought they had consumed the CHO-E beverage following the testing, and only 11 of the 22 final participants guessed correctly (50%).

There were a number of significant effects identified with the CHO-E solution when compared to the placebo. For the purpose of displaying the findings, results will be presented in three main sections:

1. Physiological and psychological results
2. Skill test results
3. Match analysis results

4.1. Physiological and psychological results

4.1.1. Blood glucose and lactate concentrations

There was a significant increase (trial, time and trialxtime effects) in blood glucose concentration following CHO-E ingestion which was not observed during the placebo trials. However, no differences were observed for blood lactate response between trials at any of the sample times (Figure 3).

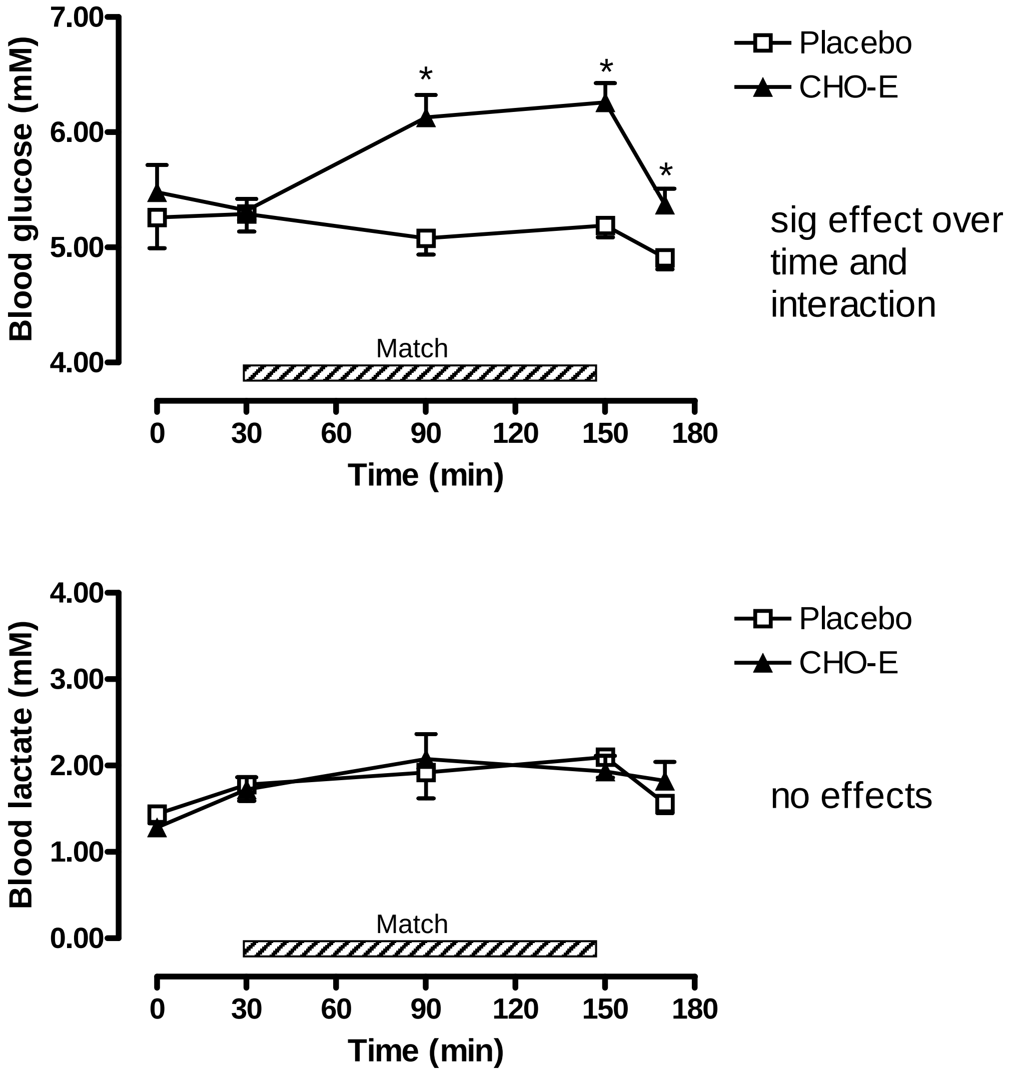


Figure 3. Blood glucose (top panel) and blood lactate (bottom panel) concentrations prior to, during and following a 2 hour period of match-play with ingestion of placebo or carbohydrate-electrolyte (CHO-E) drinks. All values are mean ± SEM.

4.1.2. Body mass

There were no differences observed between the CHO-E and PL trials in terms of body mass at baseline or post-match, or in sweat rates (Figure 4). These results suggest that the volume of fluid ingested during each trial was sufficient to replace sweat losses. The results also indicate that similar environmental conditions were experienced during each trial. Mean temperature and humidity for the CHO-E and PL trials were 21.3°C ± 1.1 / 37.1% ± 4.5 and 21.8°C ± 2.1 / 35.4% ± 3.1 respectively. These results showing no significant difference between trials for body mass and sweat rate indicate that players maintained adequate hydration levels throughout both the PL and CHO-E trials.

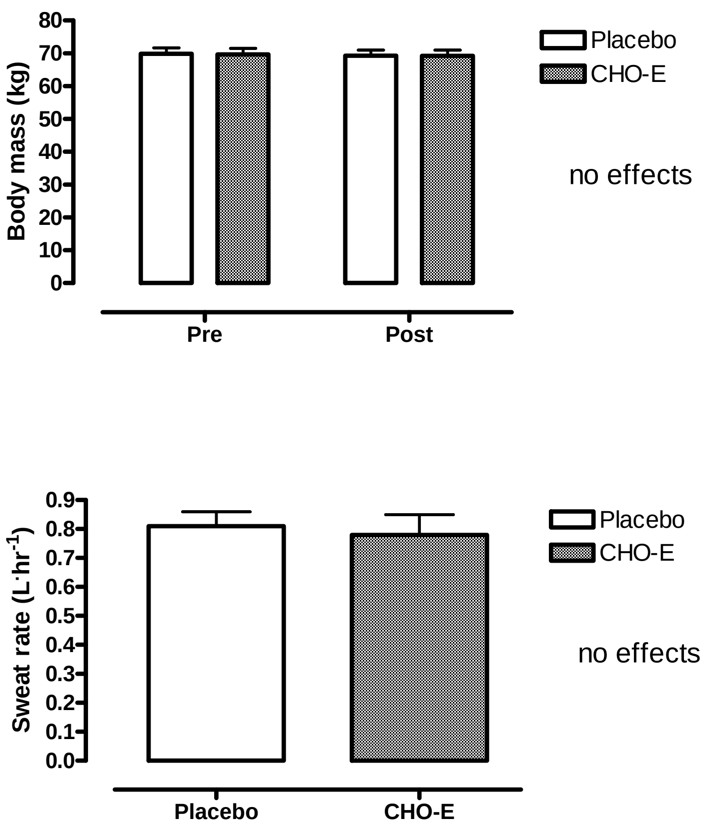


Figure 4. Body mass pre- and post- trial (top panel) and sweat rate (bottom panel) with ingestion of placebo or carbohydrate-electrolyte (CHO-E) drinks. All values are mean ± SEM.

4.1.3. Urine volume and osmolality

There was no significant difference identified between the placebo and CHO-E trials in terms of urine volume, however urine volume did increase pre- to post- trial for both conditions (Figure 5). There was also a significant interaction in urine osmolality with an increase pre- to post- trial for the CHO-E drink when compared to a decline during the PL (Figure 5).

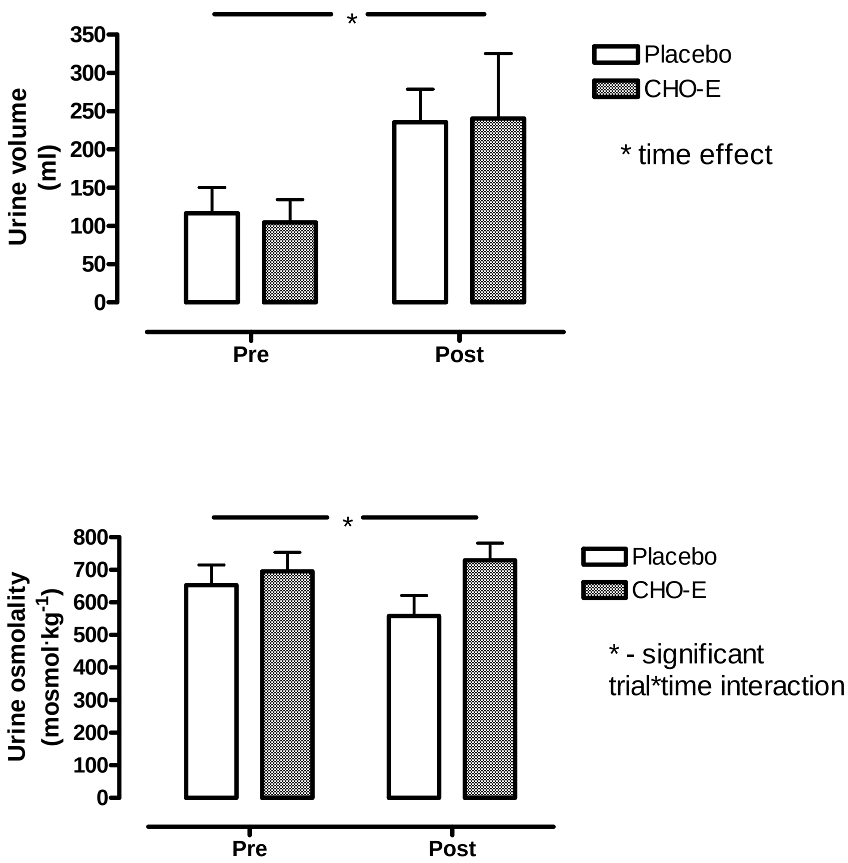


Figure 5. Urine volume (top panel) and urine osmolality (bottom panel) pre- and post- trial with ingestion of placebo or carbohydrate-electrolyte (CHO-E) drinks. All values are mean ± SEM.

4.1.4. Psychological measurements

Subjects reported that they felt more energetic (General Activation) and more tense (High Activation) in comparison to baseline score at one hour into the match (at 90 minutes) during the CHO-E trial only (Table 7). No other psychological effects were identified through the AD-ACL, feeling scale or arousal scale in either the placebo or the CHO-E trials.

Table 7. Psychological measures taken throughout the trials with ingestion of placebo or carbohydrate-electrolyte (CHO-E) drinks

* - Indicates significant difference from 0 time point within that trial.

Psychological Measurement			Time (min) into the trial					
			0 (In the lab)	10	30	90	150	170
Feeling Scale		**Placebo**	1.2 ± 2.3	1.7 ± 1.8	1.6 ± 1.7	1.4 ± 2.2	1.2 ± 2.2	0.5 ± 2.4
		CHO-E	1.0 ± 2.3	1.7 ± 2.1	0.9 ± 2.1	1.4 ± 2.3	1.5 ± 2.4	1.1 ± 1.7
Felt Arousal		**Placebo**	2.6 ± 1.0	3.4 ± 0.8	3.5 ± 1.0	3.4 ± 1.3	3.0 ± 1.3	2.6 ± 0.9
		CHO-E	2.4 ± 1.0	3.3 ± 1.0	3.3 ± 0.9	3.5 ± 0.8	3.1 ± 1.2	2.9 ± 0.9
AD-ACL	**Energetic**	**Placebo**	2.1 ± 0.6	2.7 ± 0.6	2.6 ± 0.6	2.6 ± 0.9	2.3 ± 0.9	2.1 ± 0.8
		CHO-E	1.9 ± 0.7	2.6 ± 0.8	2.6 ± 0.8	2.8 ± 0.7*	2.4 ± 0.8	2.3 ± 0.7
	Calm	**Placebo**	2.3 ± 0.6	1.7 ± 0.4	1.6 ± 0.5	1.7 ± 0.5	1.9 ± 0.6	2.0 ± 0.7
		CHO-E	2.4 ±0.6	1.8 ± 0.5	1.7 ± 0.5	1.7 ± 0.6	1.7 ± 0.6	1.9 ± 0.6
	Tired	**Placebo**	2.3 ± 0.9	1.8 ± 0.7	1.7 ± 0.8	1.7 ± 0.6	2.0 ± 0.7	2.2 ± 0.8
		CHO-E	2.3 ± 0.9	1.8 ± 0.7	1.8 ± 0.8	1.8 ± 0.7	1.9 ± 0.7	1.9 ± 0.7
	Tense	**Placebo**	1.2 ± 0.3	1.4 ± 0.5	1.4 ± 0.3	1.5 ± 0.5	1.4 ± 0.5	1.3 ± 0.3
		CHO-E	1.2 ± 0.3	1.4 ± 0.5	1.6 ± 0.5	1.7 ± 0.6*	1.6 ± 0.5	1.4 ± 0.4
RPE		**Placebo**		10.7 ± 1.4	13.0 ± 1.6	13.2 ± 1.5	13.9 ± 1.8	14.2 ± 2.0
		CHO-E		10.4 ± 1.8	13.1 ± 1.7	13.6 ± 1.8	14.0 ± 2.3	13.6 ± 1.7

4.2. Skill test results

4.2.1. Skill test total score, Groundstroke total score and Serving total score

There were no significant differences observed between the CHO-E and the placebo trials for total skill test scores (groundstroke and serve score combined), groundstroke total score or serve total score (Figure 7). In addition, there was no decline in skill test score pre- to post- match for the placebo trial.

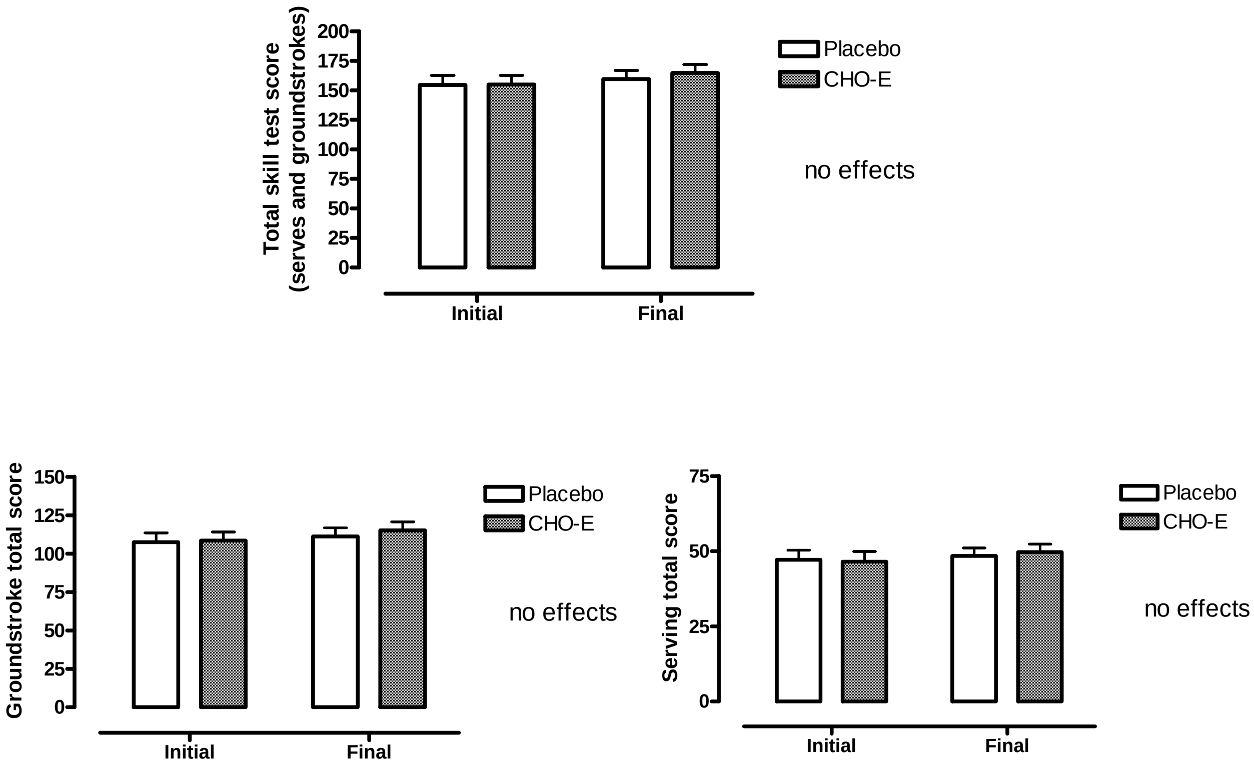


Figure 7. Skill test total score (top panel), skill test groundstroke total score (bottom left panel) and skill test serving total score (bottom right panel) pre- and post- 2 hour tennis match with ingestion of placebo or carbohydrate-electrolyte (CHO-E) drinks. All values are mean ± SEM.

4.2.2. Skill test groundstroke score and service score by zone

There were no significant differences highlighted between the CHO-E drink and the placebo in terms of groundstroke or serve scores when broken down by scoring zone (Table 8).

Table 8. Groundstroke and service score breakdown by scoring zone during the Skill Tests with ingestion of placebo or carbohydrate-electrolyte (CHO-E) drinks. All values are mean ± SEM.

Stroke	Skill Test	Trial	Total number of points scored from each zone			
			#4's ± SEM	3's ± SEM	2's ± SEM	1's ± SEM
Groundstroke Score Breakdown	Initial ST	Placebo	43.8 ± 17.0	39.7 ± 14.2	20.1 ± 8.9	3.8 ± 2.0
		CHO-E	46.4 ± 13.3	39.4 ± 15.1	19.4 ± 8.3	3.3 ± 2.5
	Final ST	Placebo	45.8 ± 14.2	40.4 ± 14.1	21.8 ± 8.1	3.2 ± 2.0
		CHO-E	50.0 ± 14.6	41.3 ± 17.0	20.3 ± 7.3	3.5 ±1.5
Service Score Breakdown	Initial ST	Placebo		36.1 ± 14.7	10.4 ± 4.6	0.6 ± 0.9
		CHO-E		36.5 ± 17.1	9.3 ± 4.6	0.6 ± 0.7
	Final ST	Placebo		35.7 ± 13.3	11.5 ± 4.0	1.2 ± 1.2
		CHO-E		39.3 ± 12.3	9.6 ± 4.6	0.8 ± 1.0

\# 4's ± SEM = total number of balls hit during the skill that landed in the target scoring zone for four points

4.2.3. Speed of serve during the skill tests

There were no significant differences between the two trials in terms of speed of serve during the skill tests (Figure 8).

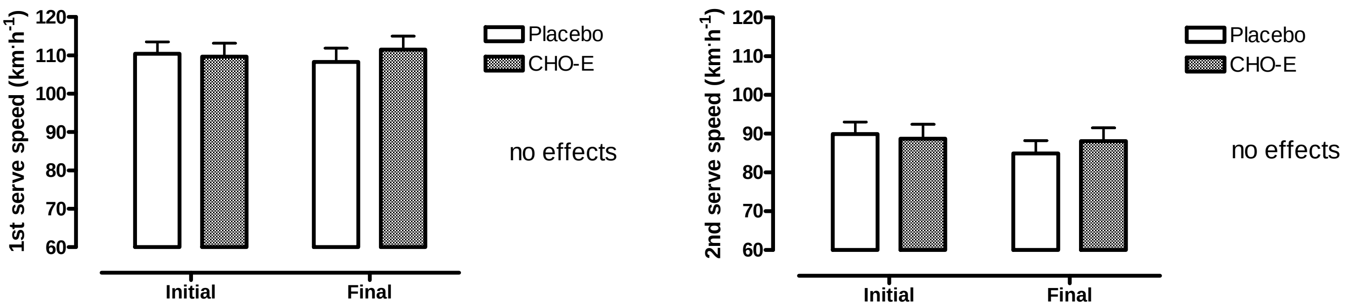


Figure 8. Speed of first serve (left panel) and second serve (right panel) as measured during initial and final skill tests with ingestion of placebo or carbohydrate-electrolyte (CHO-E) drinks. All values are mean ± SEM.

4.2.4. Heart rate recorded during the skill tests

There was also no difference between average heart rate recorded during the skill tests (Figure 9).

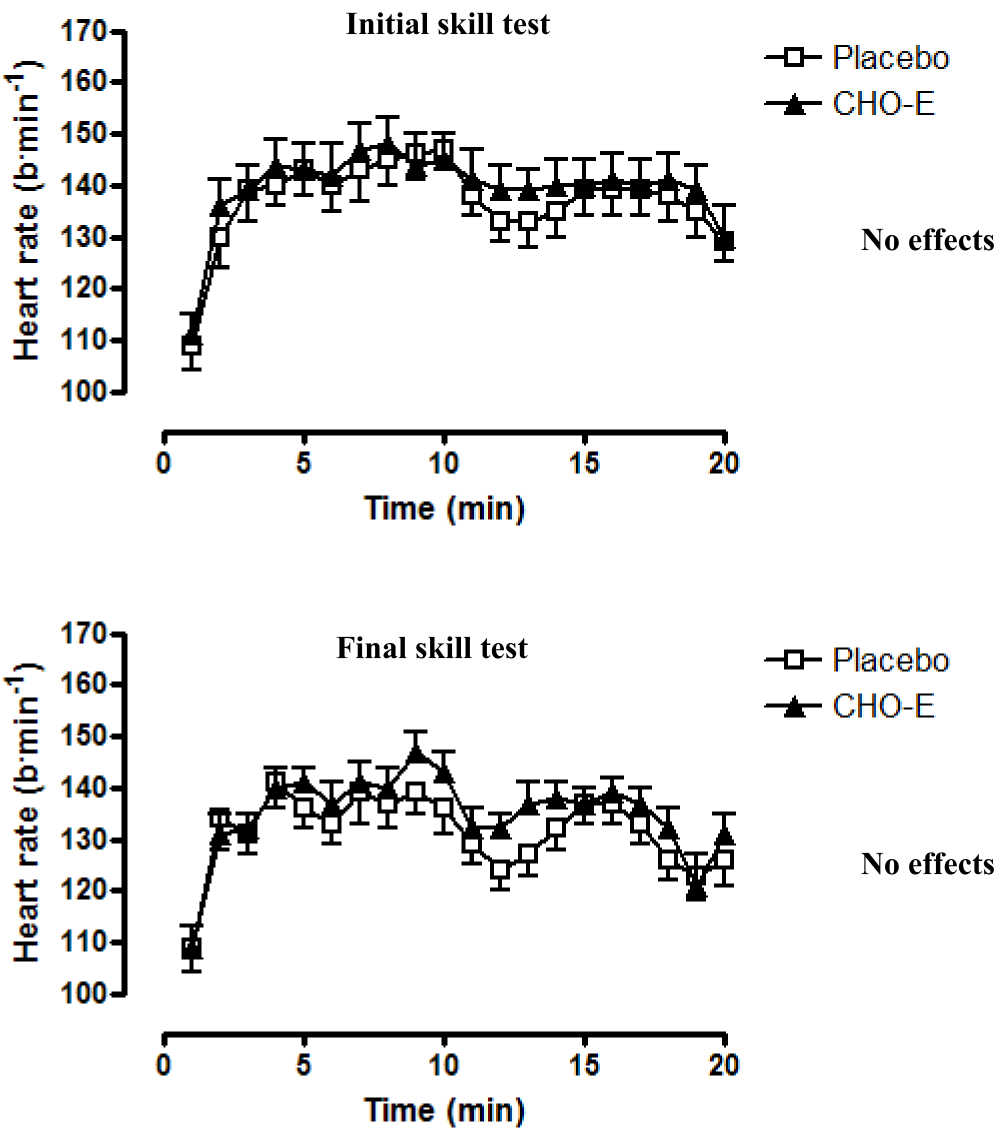


Figure 9. Participants' heart rate recorded during the initial skill test (top panel) and final skill test (bottom panel) with ingestion of placebo or carbohydrate-electrolyte (CHO-E) drinks. All values are mean ± SEM.

4.3. Match analysis results

4.3.1. Serve Success

In total, participants served a mean ± SEM of 121 ± 3 serves on the PL, of which 89 ± 2 were first serves and 32 ± 1 were second serves, in comparison to 123 ± 3 serves on the CHO-E, of which 93 ± 3 were first serves and 30 ± 2 were second serves. Subjects on the CHO-E drink had a higher success rate of all serves by 2% when on the CHO-E than PL (68% on CHO-E and 66% on PL). More notably, percentage of successful 1st serves and serves from the advantage side were both 4% higher on CHO-E than on PL (65% and 70% respectively on CHO-E and 61% and 66% respectively on PL) (Figure 10).

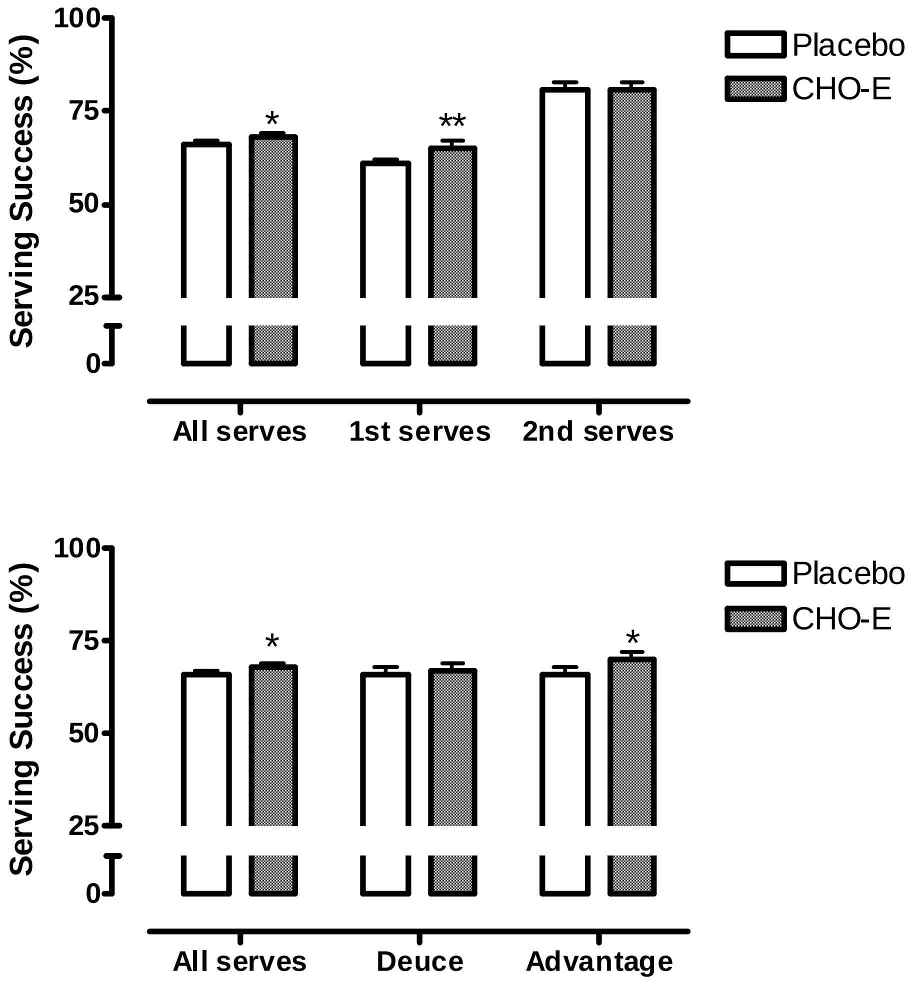


Figure 10. Serve success rates recorded during the 2 hour tennis match for All serves, 1st serves and 2nd serves (top panel) and All serves, serves to the deuce side and serves to the advantage side (bottom panel), with ingestion of placebo or

carbohydrate-electrolyte (CHO-E) drinks. * indicates significant difference between trials (p<0.05); ** indicates significance difference between trials (p<0.01). All values are mean ± SEM.

When the service data were broken down by set there were no significant differences found (Figure 11).

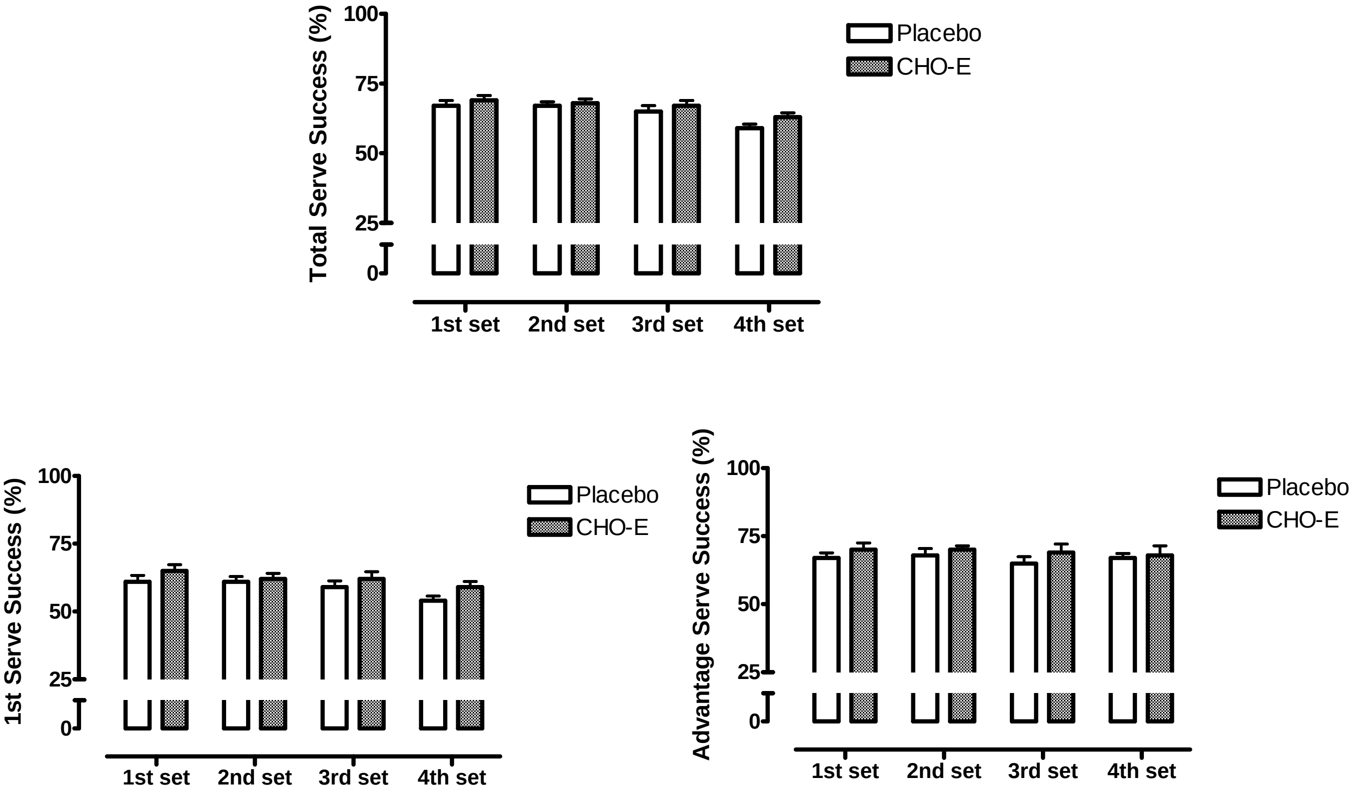


Figure 11. Serve success rates recorded during the 2 hour tennis match and broken down by set for Total Serves (top panel), 1st serves (bottom left panel) and Serves to the Advantage Side (bottom right panel), with ingestion of placebo or carbohydrate-electrolyte (CHO-E) drinks. All values are mean ± SEM.

Data also were analysed to examine whether the change in blood glucose response to feeding was related to change in 1st serve or serve to the advantage side success. Results showed no relationship (r=0.14, p=0.54 for the association of blood glucose change to change in 1st serve percentage, and r=0.02, p=0.94 for the association between change in blood glucose to change in advantage serve percentage).

In addition, even though the participants performed more total serves in the court on the CHO-E trial, they did not actually win any more points from it (Figure 12).

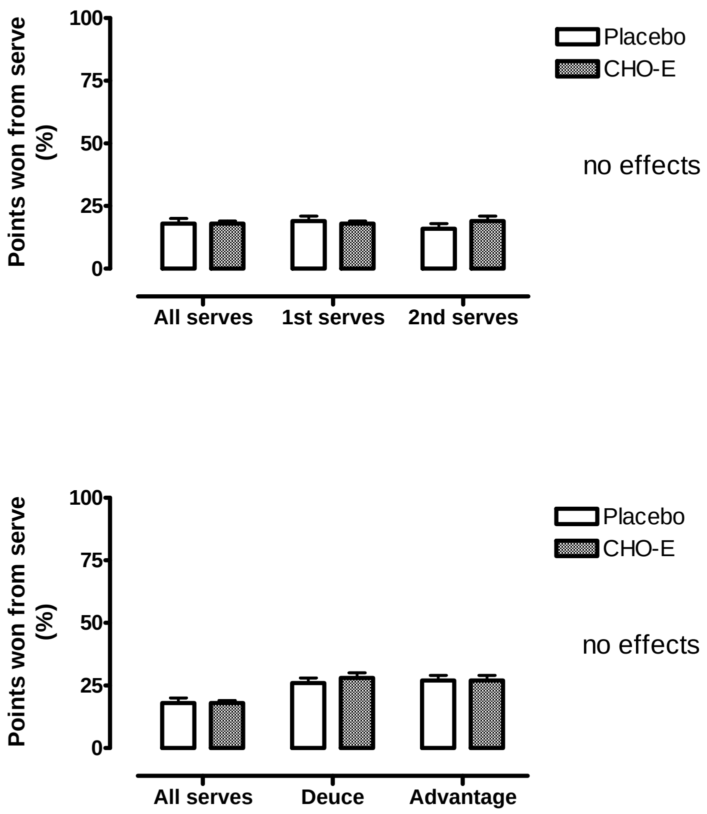
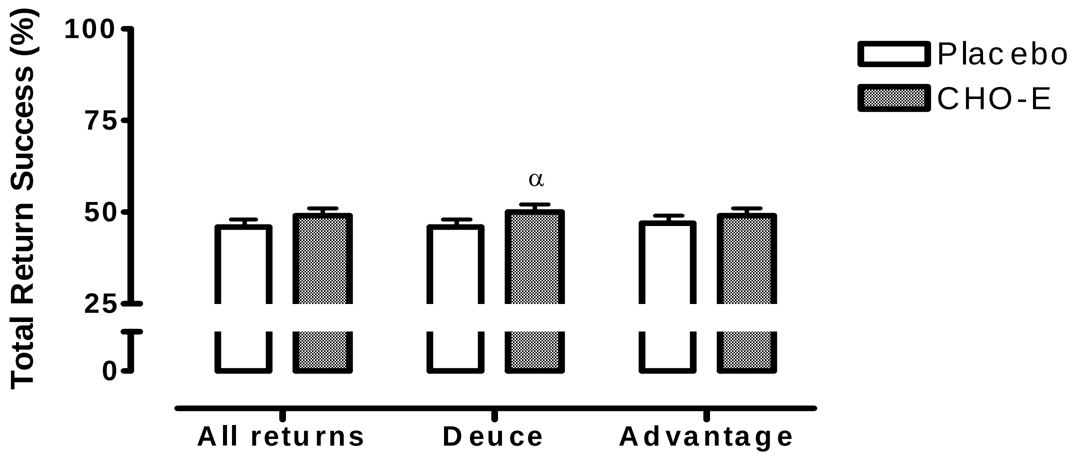


Figure 12. Percentage of points won during service games for All serves, 1st serves and 2nd serves (top panel) and All serves, serves to the deuce side and serves to the advantage side (bottom panel), with ingestion of placebo or carbohydrate-electrolyte (CHO-E) drinks. All values are mean ± SEM.

For the purpose of analysis, players were ranked based on their placebo trial serving success percentage, and no association was found between this ranking and the changes observed in percentage of first serve success rates ($r=0.13$, $p = 0.57$) nor advantage serve success rates ($r=0.18$, $p = 0.43$).

4.3.2. Return Success

Results showed that the return of serve from the deuce side for participants on the CHO-E trial was close to being significantly more successful (p=0.08) than when on the placebo trial (Figure 13), as participants on the CHO-E drink returned an average of 4% more serves successfully into the court than when on PL (50% return success on CHO-E compared to 46% on PL).



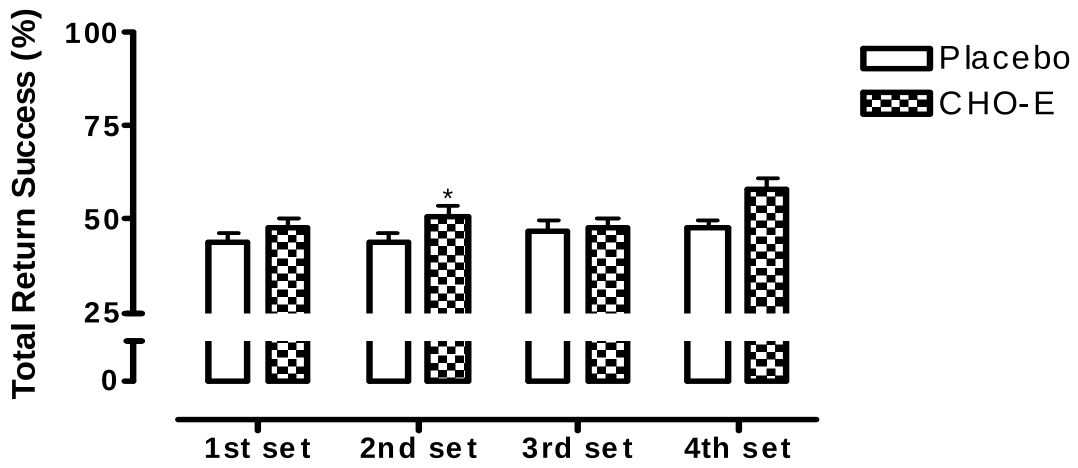
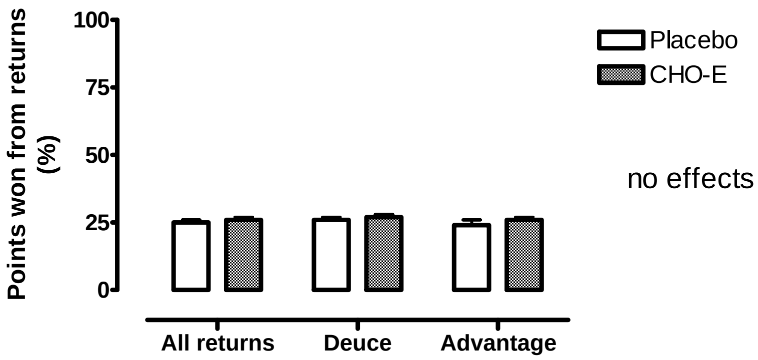


Figure 13. Percentage of total returns that were successful for All returns, returns from the Deuce side and returns from the Advantage side (top panel) and percentage of total returns that were successful when broken down by set (bottom panel), with ingestion of placebo or carbohydrate-electrolyte (CHO-E) drinks. α indicates near significant effect. * indicates significant difference between trials

($p<0.05$). α indicates nearly significant difference between trials ($p<0.08$, n=45 for 80% power, n=60 for 90% power). All values are mean ± SEM.

In addition, participants on the CHO-E drink did return significantly more serves successfully during the second set of the match when ingesting CHO-E (51% compared to 44% successful returns on PL, Figure 13). However, similar to the service results, even though participants were successfully returning more serves, they were not actually winning more points as a result (Figure 14).



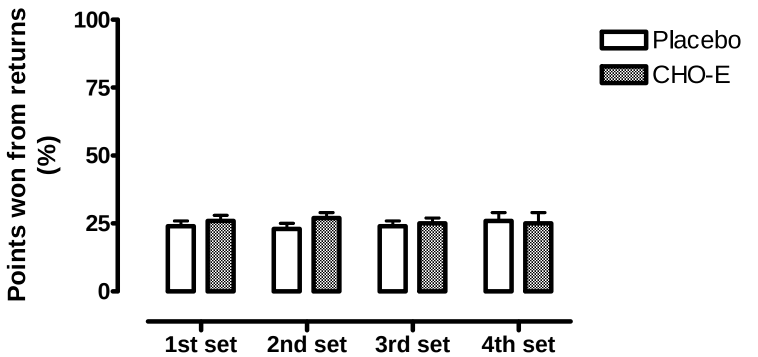


Figure 14. Percentage of points won during return of serve games for All returns, returns from the Deuce side and returns from the Advantage side (top panel) and percentage of points won during return of serve games as broken down by set (bottom panel), with ingestion of placebo or carbohydrate-electrolyte (CHO-E) drinks. All values are mean ± SEM.

4.3.3. Rallies

There were no significant differences identified between the placebo and CHO-E trials in terms of total number of rallies or total number of rallies by set (Figure 15).

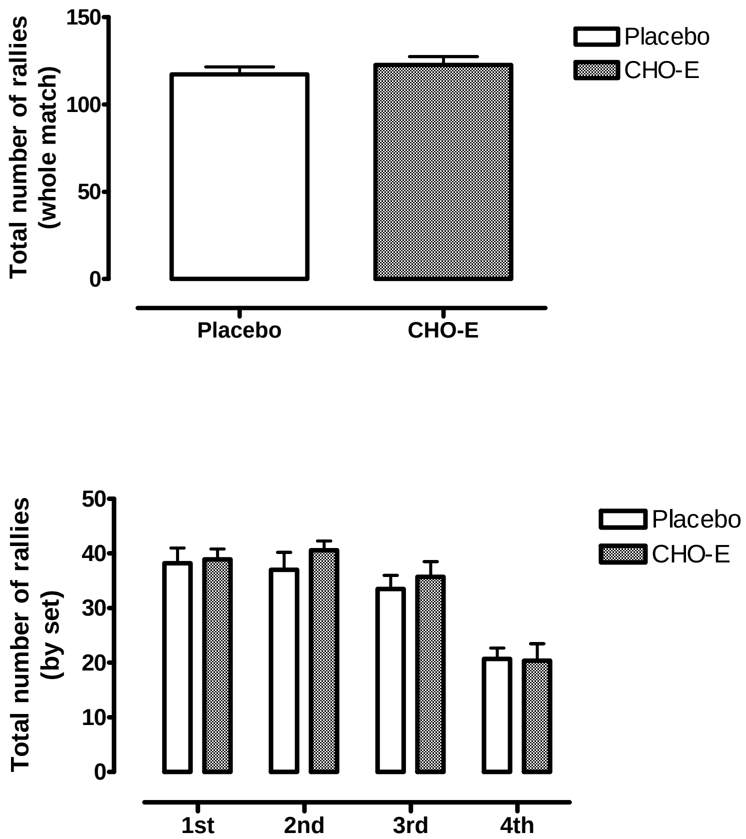


Figure 15. Total number of rallies encountered by participants during the whole match (top panel) and during each set of the match (bottom panel), with ingestion of placebo or carbohydrate-electrolyte (CHO-E) drinks. All values are mean ± SEM.

The average rally length on both the CHO-E and PL trials was 4 ± 1 shots. This means that in an average rally, 50% of the shots were either a serve or a return.

4.3.4. Unforced Errors

Similarly, there was no significant difference identified in the number of unforced errors hit, either for total number of unforced errors throughout the whole match or number of unforced errors by set (Figure 16).

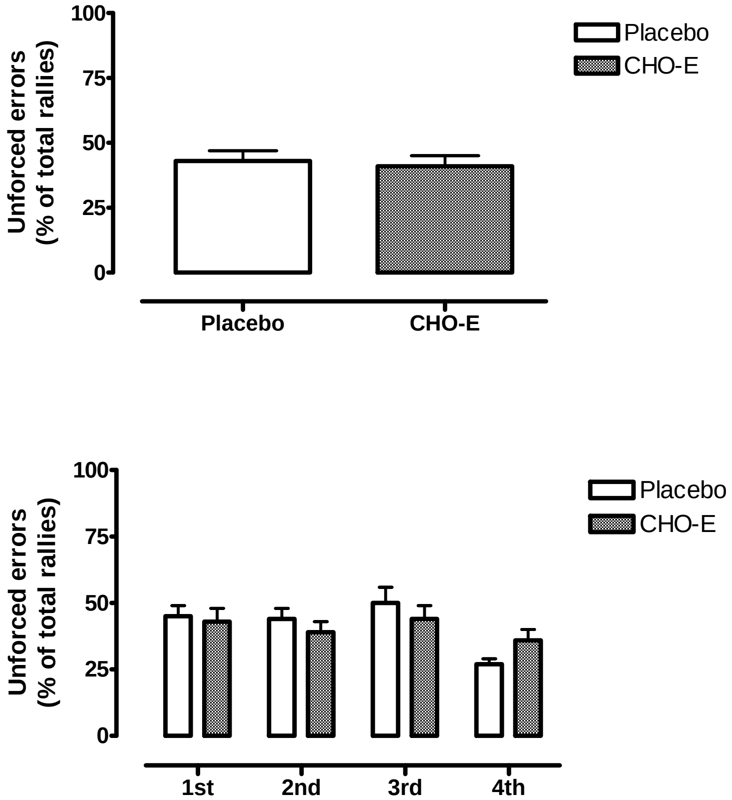
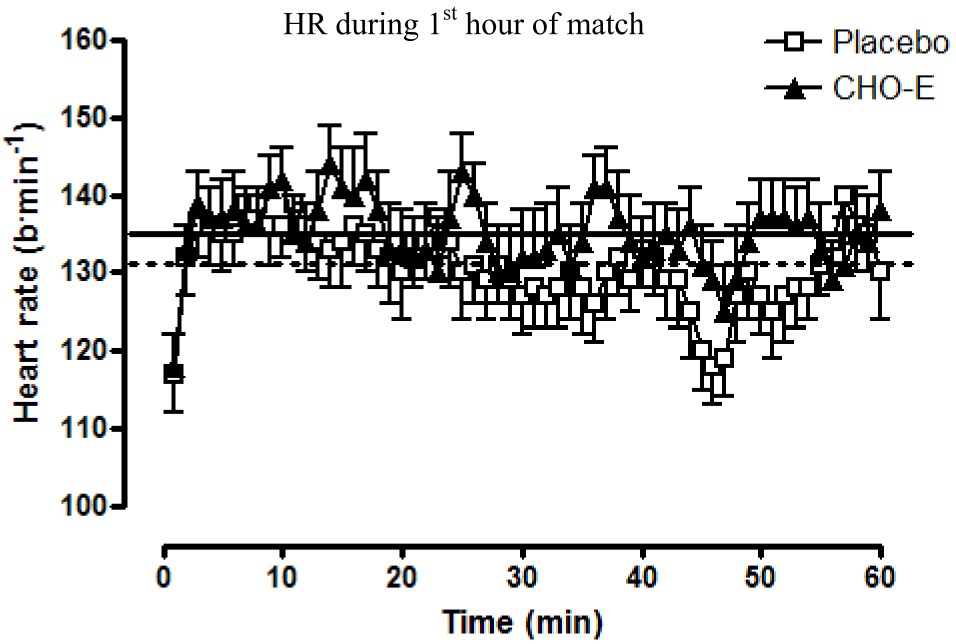


Figure 16. Total percentage of unforced errors during the enitre tennis match (top panel) and during each set of the tennis match (bottom panel), with ingestion of placebo or carbohydrate-electrolyte (CHO-E) drinks. All values are mean ± SEM.

4.3.5. Participants' Heart Rates During the Match

No significant differences were identified between trials for the participants' heart rate during the first and second hour of the match (Figure 17).



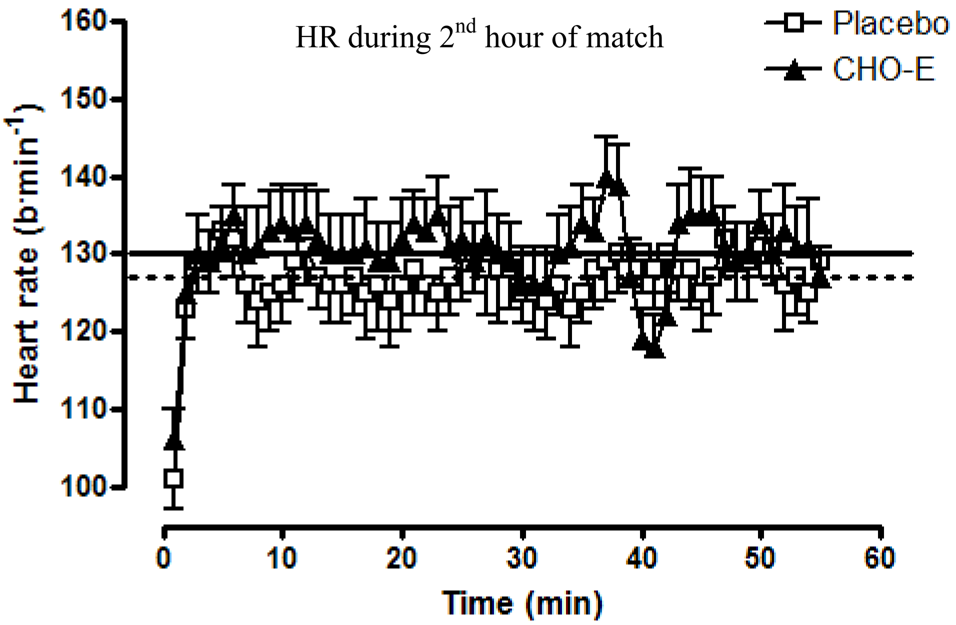
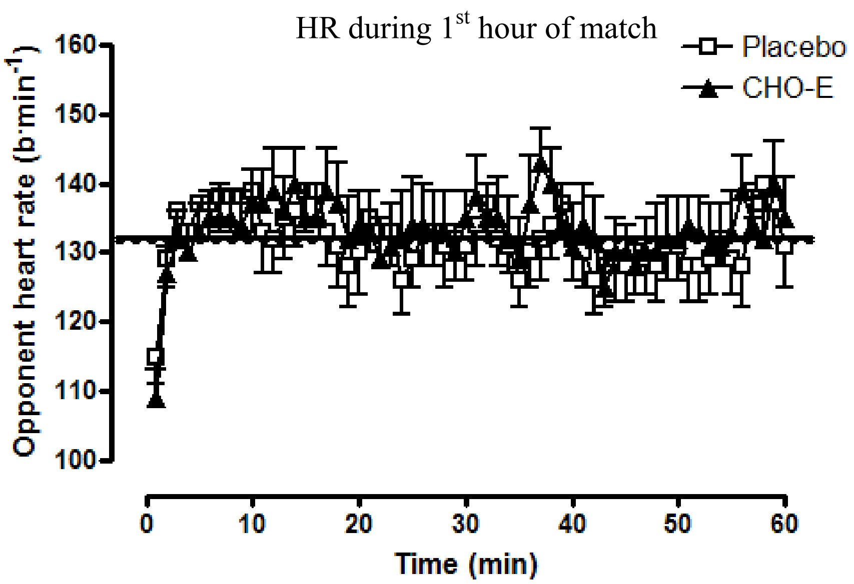


Figure 17. Participants' heart rate values during the 1st and 2nd hours of the match. Solid line and dotted line on each figure represent overall mean ± SEM values for CHO-E and PL trials, respectively.

Opponent's Heart Rate During the Match

No significant differences were observed between the placebo and CHO-E trials with regards to the opponents' heart rate during the first and second hour of the match (Figure 18).



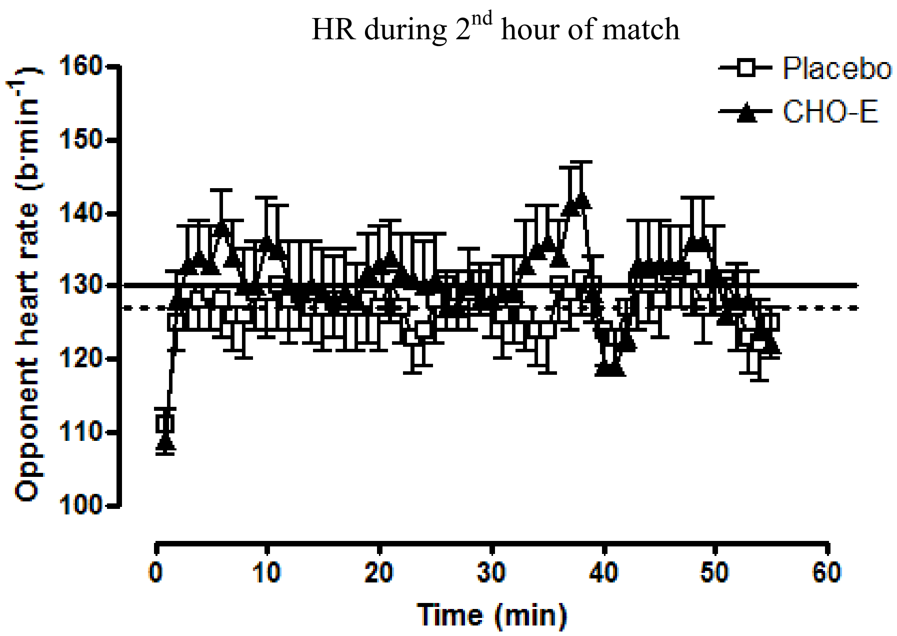


Figure 18. Opponents' heart rate values during the 1st and 2nd hours of the match. Solid line and dotted line on each figure represent overall mean ± SEM values for CHO-E and PL trials, respectively.

4.3.6. Heart Rate and Accelerometry Zone Data

Accelerometer data indicated that subjects spent significantly less time doing low intensity activity and more time in a moderate intensity activity zone during the CHO-E trial (using intensity activity zones as defined by Ekelund et al., 2005). Heart rate zone data showed a similar pattern of intensity zones to the accelerometer data; however no significant differences were identified.

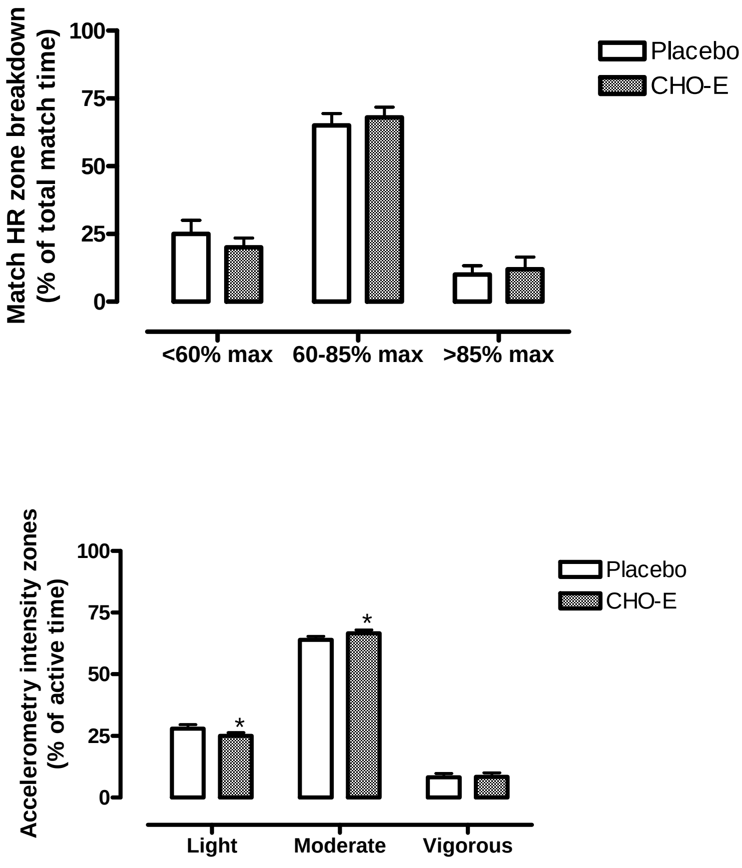


Figure 19. Breakdown of participants' heart rates by zone (top panel) and accelerometry intensity zones (bottom panel) during the two hour tennis match, with ingestion of placebo or carbohydrate-electrolyte (CHO-E) drinks. All values are mean ± SEM. * indicates a significant different between CHO-E and placebo trials.

Chapter 5

DISCUSSION

The main findings from the study indicate that CHO-E drink ingestion during a tennis match may elevate blood glucose concentration, increase overall percentage of successful serves and increase return success rates. These changes also may be linked to increased perceived activation and increased intensity of movement sustained on court. However, 2 hours of match play did not induce sufficient fatigue to alter skill test scoring ability as no significant differences were observed pre- to post- trial on the PL.

5.1. Physiological / Psychological Effects

Previous researchers have suggested that the deterioration in skill observed from fatigue in tennis could be the result of hypoglycaemia, dehydration, hyperthermia or central disruption (Davey et al., 2002; Hornery et al., 2007b; Noakes, 2000). Although we did not record values of core body temperature for the participants, results showed that ambient temperature and humidity were not different between trials. There is therefore no reason to expect core body temperature to be different between trials. From both urine and body weight analysis it is clear that the volume of fluid and electrolyte levels ingested during both the CHO-E and placebo trials was adequate to effectively maintain hydration status of the participants. In addition, individual sweat rates were similar between the two trials. In this way, it is unlikely that either hyperthermia or dehydration had a major role to play in skill deterioration in this investigation.

Analysis of blood glucose concentration on five different occasions throughout the testing revealed a significant increase in values during the CHO-E trial in comparison to the placebo trial. These findings are consistent with previous literature on carbohydrate ingestion and tennis, which found blood glucose concentration to increase relative to a placebo following carbohydrate supplementation (McCarthy et al., 1995; McCarthy, 1997; Mitchell at al., 1992). Blood glucose concentration during the placebo trial actually remained fairly consistent throughout the match and only began to drop markedly after 150 minutes. However, the values still did not reach hypoglycaemic levels (<3.5 mmol/l).

There were no significant differences observed in blood lactate concentration for the two trials, which suggests that ingestion of carbohydrate during a tennis match does not affect a player's ability to remove lactate from their system. Throughout both trials, mean levels of lactate actually remained very low (1.8 ± 0.5 mmol/l during the placebo trial in comparison to 1.8 ± 0.6 mmol/l during the CHO-E trial). This is consistent with previous research that found blood lactate concentrations during a competitive tennis match to be between 1.5 and 4.0 mmol/l (Bergeron et al., 1991; Ferrauti et al., 2001a; Fernandez at al., 2005; Fernandez-Fernandez et al., 2007; Fernandez-Fernandez et al., 2008; Mendez-Villanueva et al., 2007b; Reilly & Palmer., 1993; Smekal et al., 2001). Participants were therefore found to be working at an intensity level that either did not create a significant build up of lactate or, if players were forced to work anaerobically at any time, then they had sufficient rest periods during which their body was able to remove the lactate from their system.

There were no significant differences observed with regards to levels of feeling and felt arousal between trials, however participants on the CHO-E reported that they felt more energetic (General Activation) and also more tense (High Activation) at approximately one hour into the match (at 90 minutes into the trial). These changes of enhanced perceived activation are consistent with previous reports of CHO-E ingestion during prolonged exercise (Backhouse et al 2007), and coincide with significantly higher levels of blood glucose at 90 minutes.

Previous psychological literature on arousal, including the Predictions of Catastrophe Theory (Hardy, 1996) and the Predictions of Conscious Processing Theory (Masters, 1992), suggest that an increase in arousal and feelings of tension can lead to impaired performance. As a result, sport psychologists have developed numerous pre-performance routines and techniques to try to help athletes to relax. Results from the present investigation indicate that carbohydrate feeding can help to increase levels of activation (energy and tension) above resting levels, which was in turn associated with increased serve and return success.

One possible explanation for the increased levels of energy and tension resulting in improved performance is if the players on the placebo trial were actually experiencing sub-optimal arousal levels. Several psychological models of arousal indicate that there is an optimal level of arousal at which athletes are most likely to perform to their maximum potential (Landers & Boutcher, 1993). This level will vary between individuals, however arousal levels either above or below this point are more likely to result in reduced performance.

Due to the stop-start nature of a tennis match, it takes a great deal of skill and discipline to maintain concentration and optimal levels of arousal throughout the entire duration of a tennis match. As match time increases, this task becomes even more challenging. It is common for players to experience a drop in concentration and levels of arousal, in particular at the beginning of the second set, where the score returns to 0-0 and therefore the momentum of the match has the potential to change (Higham, 2000). If CHO-E ingestion can have a positive impact centrally (Carter et al., 2004; Chambers et al., 2009), it is not surprising that this benefit could potentially have a more significant effect during the second set, or one hour into the match, when the match is neither close to beginning nor ending and at a time when both concentration and arousal levels may decrease slightly.

Pribram and McGuinness (1975) conducted a review of neuropsychological and psychophysiological data on attention, which suggested that there are three separate but interacting neural systems. The first system controls arousal, which is defined in terms of "phasic physiological responses to input," the second system controls activation, which is defined in terms of "tonic physiological readiness to respond," and the third system controls coordinates both arousal and activation (effort). In this way, it is possible that activation and arousal are two separate but interacting systems, and therefore optimal performance may occur when players reach optimal levels of both activation and arousal simultaneously. In addition, if arousal and activation are two separate entities, it is possible that a player in this study may have had high levels of activation without equivalent levels of arousal that may have been detrimental to performance.

A significant increase in RPE over time was noted for both trials, however there was no significant difference reported between RPE on the CHO-E and placebo trials. Mean RPE values recorded during match play were similar to those reported in previous investigations from Fernandez-Fernandez et al. (2008), who reported a mean RPE value of 12.2 ± 2.4 (range 7 to 17), and Fernandez et al (2005) who found mean RPE to be 12.5 ± 2.1 during competitive tennis match play. These results suggest that the intensity of play during the match trials was representative of the intensity usually experienced in a real tennis competition.

Similarly, RPE values for the final skill test following ingestion of either the CHO-E or placebo beverage were 14.2 ± 1.9 (range 11 to 19) and 13.6 ± 1.7 (range 11 to 17) respectively. These values indicate that the skill test was representative of the perceived exertion that players experience during a real tennis match (Fernandez-Fernandez et al., 2008). However, previous studies that have used skill tests to analyse performance have elicited higher levels of exertion than would normally be seen in a real tennis match. For example, Davey et al. (2002) used skill tests to elicit volitional fatigue in the participants. Players subsequently reported peak RPE scores of 20 ± 0 from as early as 75% into the intermittent test, along with a peak blood lactate concentration of 9.6 ± 0.9 mmol/l recorded 25% into the intermittent test. In addition, high blood lactate concentrations were identified as one possible explanation during this study for the observed decline in performance. These levels of RPE and blood lactate are significantly higher than any values which have been recorded in previous research using a real match situation, therefore it is questionable how valid such findings are when applied to a real match situation.

Overall, players were found to have maintained adequate levels of hydration throughout both the CHO-E and placebo trials. Elevated blood glucose concentration was found to coincide with enhanced feelings of activation one hour into the match, however blood lactate concentration did not increase significantly during either the CHO-E or placebo trial. The RPE values also suggest that the skill tests were representative of intensity levels experienced during actual match play.

5.2. Skill test results

Serve and groundstroke accuracy and speed of serve results from the skill test show no significant differences between either the CHO-E and placebo trials or indeed between the pre- and post- match skill tests. These findings therefore indicate that ingestion of a carbohydrate electrolyte beverage did not help to improve skill performance as assessed by the skill test in relation to serve and groundstroke accuracy and speed of serve. More importantly, results from the skill test suggest that following 2 hours of competitive tennis match play, players were not fatigued to a point where their ability to maintain speed and accuracy of ground strokes or serves to a set target was affected. In addition, participants' heart rate values were not significantly different between trials, which indicates that they were able to work at a similar intensity both with and without carbohydrate ingestion and also both pre- and post- a 2 hour tennis match.

It has been suggested that CHO-E drink ingestion may to help maintain skill performance when players are fatigued rather than to enhance it (Bottoms et al., 2006). As players in this study did not show signs of fatigue or reduced performance between initial and final skill tests on the placebo trial, it is not surprising that results from the skill test do not show improved performance with CHO-E ingestion. In this way, 2 hours of match play probably did not induce sufficient fatigue to affect this type of skill assessment task, unlike previous research that has used ball machine tests to elicit fatigue in players and subsequently found a beneficial effect of CHO-E ingestion on skill performance (McCarthy, 1997; Vergauwen et al., 1998a).

As the skill test was only 20-30 minutes in duration, it is also possible that subjects were able to re-focus their attention for the short period of time. In addition, subjects did not have to make any tactical decisions during the test, which would mean they were able to focus their full attention on execution of the skill. Schmidt and Wrisberg (2000) defined attention as "focalization and limitation of information processing resources", which reinforces the point that a person's ability to process information is limited. This limited attentional capacity means that humans can concentrate on only a small amount of information at one time, which reduces the ability of a person to process information (Schmidt and Wrisberg, 2000). The skill test therefore may not accurately reflect the psychological demands of tennis, and the stop-start nature of the game.

The performance protocol measures in previous research has been a major limitation to the results, where investigators have attempted to identify the effects of fatigue or carbohydrate ingestion on performance through quantification of accuracy and velocity of skill (Davey et al., 2002; Vergauwen et al., 1998a). This measurement of skill has frequently been measured solely in the participants' ability to hit serve or ground strokes aimed at specific target areas on the court (Davey et al., 2002; McCarthy, 1997; Struder et al., 1999). In addition, poor target sizes and scoring systems have reduced the capacity to detect subtle performance changes that may be associated with fatigue or carbohydrate ingestion.

The use of a ball machine in test conditions does reduce the variability and improve the standardisation of skill assessment in tennis; however it also removes a large majority of the cognitive processes that are essential to tennis performance. Any player can obtain a large amount of information from their opponent, for example the position of the opponent on the court, tactical indications as to where the opponent might play the next shot, the physical condition of the opponent etc. The player will also have to consider how the opponent plays tactically in order to tailor their own tactics to target their opponent's weaknesses. Possibly of most importance though, is the vast amount of psychological activity that players have to control and use to their advantage during match play, are entirely excluded through the use of a skill test and ball machine.

Overall, skill test results indicate that 2 hours of tennis match play was not sufficient to induce fatigue in the participants, as no significant decline in skill test scores were observed pre- to post- match in either the carbohydrate or placebo trial. In addition, no significant difference was observed in skill test scores between trials. Future research should consider how representative tennis skill tests actually are of real match play situations, and therefore how accurate any conclusions drawn using skill tests are with regards to actual tennis match play.

5.3. Match analysis results

As participants on the CHO-E drink had a higher success rate for all serves (by 2%), and more specifically 1st serves (by 4%) and serves to the advantage side (by 4%), their overall service percentage was higher and therefore more consistent throughout the CHO-E trial than when ingesting the PL. When the service data were broken down by set there was no significant difference found, which suggests that the increase in service success rate was accumulative throughout the match, rather than occurring at any one point in time. This also indicates that any potential benefits of the CHO-E drink to players were spread throughout the duration of the match.

There are a few possible explanations based on previous research for the increase in service performance being identified specifically for the 1st serve and serves to the advantage side. Firstly, Bottoms et al. (2006) found that the effect of carbohydrate ingestion on skill maintenance in squash was essentially limited to the backhand side, which was suggested to be caused by the backhand being the weaker shot, as confirmed by skill test scores. McMorris and Graydon (1997) stated that more familiar tasks will present with an element of automaticity, and therefore fewer CNS resources are required for optimum performance. Automatic processing (automatcity) is a type of information processing that is fast, parallel, not attention demanding, and often involuntary, therefore is more prevalent in the later stages of learning (Schmidt and Wrisberg, 2000). In this way, as the backhand was the weaker shot, Bottoms et al. (2006) suggested that more CNS resources would be required to allow for accurate performance.

Welsh et al. (2002) proposed that fatigue is associated with a decrement in central control, which would explain why a weaker shot demanding more CNS activity could be more susceptible to fatigue. If CHO-E ingestion can help to increase CNS activity (Liu et al., 2000), then it could potentially help to maintain performance in the weaker shot more apparently than any stronger shot. However, results from the skill test showed no significant difference between the scores of serves to the deuce and advantage sides, which suggests that the advantage serve was not weaker than the deuce serve.

Welsh et al. (2002) also found that as fatigue increases and central control decreases, individuals must decrease the rate at which a task is completed in order to maintain a high degree of accuracy. In order to try to combat this decrement in performance, Welsh et al. (2002) found that individuals who ingested a CHO-E drink during high intensity intermittent activity managed to maintain speed whilst also maintaining accuracy and control of performance. In contrast, individuals on the placebo trial slowed down their speed of performance in order to maintain accuracy and control during intermittent high intensity physical activity. These results suggest that carbohydrate ingestion can lead to enhanced central nervous system control of motor units. However, again results from the skill test in this study indicate that service speed was maintained throughout the trial, as no significant difference was observed on speed of serve between pre- and post- match skill tests.

Similarly, Hornery et al. (2007c) identified a reduction in serve and ground stroke velocity and ground stroke accuracy with time rather than a disruption to homeostasis, as well as a slowing of the serve racket-arm acceleration phase. It was suggested that a central governor might therefore control power output, and that players might subconsciously reduce stroke power as fatigue increases in an attempt to prevent injury (Noakes et al., 2005). However, markers of central fatigue (prolactin) did not support this conclusion. In another study, Struder et al. (1999) observed an increased ratio of tryptophan to branched chain amino acids during prolonged tennis, with no change in prolactin, which suggests that other markers of central fatigue might be more accurate indicators of the central governor behind performance deterioration.

Taking the findings of these studies into consideration, participants' first serves may have deteriorated during the placebo trial if they had tried to maintain the speed of their first serve. In contrast, based on the findings of Welsh et al. (2002), carbohydrate ingestion may have helped the first serve more than the second due to the faster nature of the first serve or if the first serve was the less consistent shot initially. Findings also may have proved more conclusive with regards to the first serve owing to the fact that every point during the match would have begun with a first serve (mean ± SEM first serves on PL = 89 ± 2, CHO-E = 93 ± 3), however only some points would have required a second serve (PL = 32 ± 1, CHO-E = 30 ± 2). There were therefore approximately three times more first serves than second serves during each trial from which to produce a trend.

Vergauwen et al. (1998a) found percentage errors and velocity precision index (VP) to increase with fatigue on the first serve, whilst no performance response to fatigue was noted on the second serve. In addition, ingestion of CHO was found to reverse these effects. Vergauwen et al., stated that the increase in first serve errors and VP was mainly due to impaired wide serves. Furthermore, CHO tended to enhance the first serve VP index, predominantly for wide serves. The results from Vergauwen et al. are therefore similar to the results from this study, in that first serve success was found to be maintained with ingestion of CHO-E in comparison to a PL. However, Vergauwen et al. used simulated match play with a ball machine rather than a real match play situation. It is also worth noting for future research that the wide service may be more important to analyse than service down the centre of the court (down the 'T') when looking at velocity.

Alternatively, McMorris and Keen (1994) suggested that more complex tasks are more likely to be affected by arousal, and therefore require more demand from the CNS. The assumption that higher levels of arousal demand more CNS resources could provide another possible explanation for the increased serve consistency to the advantage side with carbohydrate ingestion. During a tennis match, players can only win or lose a game when serving to the deuce side at a score of 40-15 or 15-40. In contrast, players can have game point to the advantage side at scores of 40-0 / 0-40, 40-30 / 30-40 or unlimited advantage points (Table 12). In this way, it would seem logical that players may experience higher levels of arousal when serving to the advantage side, owing to the fact that they (or their opponent) will have more game point opportunities from this side, which could possibly lead to higher stress levels.

Table 12. Possible score combinations within a tennis game

	Deuce Side	**Advantage Side**
Number of possible '**game point**' score combinations	2 (40-15; 15-40)	**Unlimited** (Unlimited # of advantage points)
Number of possible **equal** score combinations	**Unlimited** (Unlimited # of deuce points)	0
Number of score combinations where the opponent is **within one point** of the player	0	**Unlimited** (Unlimited # of advantage points)
Number of score combinations where the opponent is **within two points or more** of the player	**4** (30-0; 0-30; 40-15; 15-40)	2 (40-0; 0-40)

In addition, when serving from the advantage side, the player's opponent will most likely be only one point either in front or behind them in the game (Table 12), which may again elicit higher levels of stress than when the opponent is either two or more points ahead or behind or drawing level in the game. This could therefore subsequently demand more CNS activity from the advantage side in comparison to the deuce side.

Interestingly, Davey et al. (2002) also found accuracy of serve to the advantage side to reduce by 30% with fatigue, whereas there was no change in the accuracy of serve to the deuce side with fatigue. Similarly, McCarthy (1997) found that both hitting to fatigue and hitting from one day to the next specifically affected serving accuracy to the advantage court. McCarthy also found that ingestion of a high carbohydrate (10g/kg BM) diet during recovery can help to maintain service accuracy to the right hand court in comparison to an isocaloric intake of protein and fat during recovery. All trials were performed following an overnight fast of 10 hours. The recovery diet included the subjects' normal diet plus additional energy in the form of either CHO for the CHO group or fat and protein for the control group. Both groups also consumed a standardised breakfast following the first trial, which consisted of 122g CHO for the CHO group and 18g CHO for the control group. However, neither Davey et al. (2002) nor McCarthy (1997) were able to give an explanation for the logic behind the reduced accuracy of the serve to the advantage side with fatigue.

It is unknown whether there is a relationship between the hand that a player holds the racket in and the side of a court that is more affected by fatigue on serve. Neither Davey et al. (2002) nor McCarthy (1997) reported on ratio of right-handed to left-handed tennis players. In this study, 20/22 players held the tennis racket in their right hand in comparison to 2/22 players who were left-handed. Given that more complex or challenging tasks may be more susceptible to fatigue (Bottoms et al., 2006), it is possible that serving to the advantage court is biomechanically more challenging for right-handed tennis players than serving to the deuce court. If serving to the advantage court was a more challenging shot for right-handed players than serving to the deuce court, it may subsequently be more susceptible to fatigue, in which case there may be more potential for CHO-E to help maintain performance than when serving to the deuce side.

Hornery et al. (2007a) found that as tennis match duration increased and adverse physiological conditions developed (increased heart rate, body mass deficits and heat strain), elements of both first and second service action were negatively affected. Specifically, consistency in the height of the arm at ball release, and the position and height of the ball toss were the most notable technical inconsistencies. However, while these findings suggest a relationship between physiological strain and diminished technical skill performance, Hornery et al.(2007a) found that modified coordination and timing of the service action did not actually compromise stroke outcome (velocity and accuracy). It would therefore be beneficial for future research to investigate the biomechanics of stroke technique on the serve and return in relation to serve and return success rates with ingestion of CHO-E during a tennis match.

It has been suggested in previous research that muscle force production may be another possible explanation for maintenance of performance with CHO-E ingestion (Nybo, 2003). Nybo (2003) suggested that carbohydrate ingestion may alter CNS activation and subsequently result in improved sustained maximal force production in comparison to a placebo. However, in Nybo's study hypoglycaemia developed during prolonged exercise in the placebo trial, which did not occur in this study. In another study by Bottoms et al. (2006) where no hypoglycaemia was observed, the maximal voluntary wrist flexion force output declined on both the carbohydrate and placebo trials during the fatigue test, and there was no significant difference observed between trials. Bottoms et al. (2006) did however observe an increase in skill performance with carbohydrate ingestion, therefore it was concluded that this difference was not related to localised fatigue or activation of the forearm wrist flexors. Based on previous research, it is therefore unlikely that sustained muscular force production is the mechanism behind improved serve consistency with CHO-E ingestion, as it would also not provide an explanation for the discrepancy between the deuce and advantage sides; however more research into the biomechanical changes behind serve technique with fatigue is required.

Data were also analysed to examine whether the change in blood glucose response to feeding was related to change in 1st serve or serve to the advantage side success rates. Results showed no association ($r=0.14$, $p=0.54$ for association of blood glucose change to change in first serve percentages, and $r=0.02$, $p=0.94$ for association between change in blood glucose change in advantage serve percentages), which suggests that blood glucose concentration cannot influence the outcome measures per se. Oral sensing, or the central effects of carbohydrate feeding, may therefore provide an explanation for the performance improvements, regardless of the magnitude of change in blood glucose response to feeding (Chambers et al., 2009).

Chambers et al. (2009) examined the effects of carbohydrate sensing on exercise performance and brain activity. In their first study, eight endurance-trained cyclists completed a time trial significantly faster when rinsing their mouths with a 6.4% glucose solution compared to a placebo containing saccharin. Corresponding MRI scans revealed that reward-related brain regions were activated by oral exposure to glucose, including the anterior cingulate cortex and striatum, which were unresponsive to saccharin.

Chambers et al. (2009) also examined the effects of rinsing with a 6.4% maltodextrin solution on the performance of eight endurance-trained cyclists, and found that the time to complete the cycle time trial was again significantly reduced compared to an artificially sweetened placebo. Chambers et al. (2009) concluded that the improvement in performance that is observed when carbohydrate is present in the mouth may be due to the activation brain regions believed to be involved in reward and motor control. In addition, there may be a class of so far unidentified oral receptors that respond to carbohydrate independently of those for sweeteners. These results support the findings of the present study, as change in first serve and serve to the advantage court success rates with ingestion of CHO-E showed no association with change in blood glucose. In this way, the maintenance of serve and return performance may be caused by a central effect with ingestion of CHO-E.

Data were also analysed to investigate whether players with a more consistent serve respond more or less to CHO-E feeding based on serve percentages. Players were ranked based on their placebo trial serving success percentage, and no association was identified between either changes observed in 1st serve % success ($r=0.13$, $p=0.57$) or advantage serve % success ($r=0.18$, $p=0.43$) and change in blood glucose levels. This suggests that players with an initially more consistent serve were not found to benefit any more or less than players with a less consistent serve.

Overall, it is clear that there is some benefit obtained from CHO-E ingestion with regards to serve consistency, in particular for first serves and serves to the advantage side. However, there is no previous research that suggests a possible mechanism behind these findings. Several possible suggestions can be made from previous findings as to possible mechanisms and applied to tennis. These are all based on the finding that

CHO-E ingestion has a beneficial effect on CNS activation, and therefore tasks that require higher levels of CNS activity initially are more susceptible to decline with fatigue. Examples of such tasks may include points in tennis that elicit higher levels of arousal (e.g. serving from the advantage side), activities carried out at a higher speed (e.g. first serve) or a player's weaker shot (possibly first serve or serve from the advantage side). Findings indicate that oral sensing or the central effects of carbohydrate feeding are likely to be responsible for the improved serve performance, independent of the size of the change in blood glucose response to feeding. It is unlikely that improved serve performance was the result of sustained muscular force production, and improvements were also not related to the standard of player. Further research into CNS activity and tennis is crucial before any conclusions on the mechanisms behind the effect of CHO-E ingestion on serve performance can be drawn.

Participants on the CHO-E drink also returned significantly more serves successfully during the second set of the match (51% on the CHO-E trial in comparison to 44% on the placebo trial). This finding coincides with the discovery that participants also felt significantly higher levels of activation one hour into the match, as players were likely be at some stage of the second set one hour into the match, and showed higher levels of blood glucose in comparison to the placebo at this point in the testing. Again, there is no previous research that has found a similar result with regards to return of serve in tennis; however there are a few findings from previous investigations that may provide some suggestions as to possible underlying mechanisms.

Owens and Benton (1994) associated the elevated blood glucose concentration from carbohydrate ingestion with faster reaction times, improved mental speed and faster and more efficient information processing levels due to faster decision making in comparison with the placebo. Similarly, Bottoms et al. (2006) found visual reaction time to increase with carbohydrate ingestion. Choice reaction time has also been found to improve with carbohydrate ingestion following 100 minutes of running at ventilatory threshold (Collardeau et al., 2001). The authors proposed that this improvement could be due to a reduced mental load, which subsequently would allow for greater attention to be paid to the task at hand. In this way, if players' visual reaction time increased with carbohydrate ingestion, this would subsequently allow them to react quicker to a serve and hopefully allow them to prepare earlier for the return of serve. Interestingly, Bottoms et al. (2006) found no significant difference between the carbohydrate and placebo trials with regards to auditory reaction time. In addition, neither visual nor auditory reaction time decreased with fatigue during the placebo trial, therefore carbohydrate ingestion was found to enhance reaction time rather than to restore it.

Another aspect to reacting quickly to a tennis serve is the player's ability to generate power very quickly. Explosive power depends on a number of crucial neural aspects, including high-frequency recruitment of the available motor unit pool and muscle fibres within the synergistic muscles (Green, 1997). The rate of force development (RFD) determines a muscle's ability to generate fast and forceful contractions (Aagaard et al., 2002). Therefore any mechanism that may reduce the RFD would subsequently contribute to fatigue during fast movements by decreasing the magnitude of force that can be achieved in the early phase of muscle contraction, for example reacting to return a serve as in the present study.

Both neural and peripheral factors influence RFD (Aagaard et al., 2002), with neural output to the motoneuron having a major influence in determining the magnitude of RFD (Nelson, 1996). Previous research has found a decrease in neural drive to the motor unit during high intensity intermittent exercise, similar to the intensity elicited in the present study (Nordlund et al., 2004; Taylor et al., 2000). This decreased neural drive may therefore subsequently reduce RFD and result in a reduced reaction time in tennis. However more research that is specific to RFD and tennis is required before any conclusions can be drawn with regards to reaction time and fatigue in tennis, specifically looking at ball contact point on the return of serve in relation to the body. In addition, further research is required into the impact that carbohydrates may play in reducing any decrease in RFD.

Hornery et al. (2007c) identified that little is also currently understood on the functionality of anticipatory skill under stress, or how it is affected by certain psychophysiological and central stimulants such as carbohydrates (Davis et al., 1992). Anticipation is crucial to an effective return of serve; in particular in the men's game when serves are very fast, therefore further research into the effects of carbohydrate ingestion on anticipatory skills would also be highly beneficial.

Interestingly, Fleury and Bard (1990) investigated the effects of fatigue from treadmill running at various intensities on the performance of a sensory task (peripheral threshold detection), sensory motor task (coincidence timing) and a cognitive task (recall in central vision). Findings showed that both the performance of coincidence anticipation and the cognitive task were negatively affected by maximal aerobic exercise, however peripheral vision performance increased at all intensity levels.

Overall, carbohydrate ingestion was found to improve the consistency of the return of serve; however the mechanisms behind this improvement are currently unknown. Further research is required into return of serve performance and carbohydrate ingestion before any conclusions can be drawn.

There were no significant differences identified between the placebo and CHO-E trials in terms of total number of rallies, total number of rallies by set, or number of points won (even though the data appeared to show more rallies in the 2nd an 3rd sets on the CHO-E trial). Therefore even though participants were found to increase the number of successful serves and returns during the CHO-E trial, they did not actually have significantly more rallies and were not winning significantly more points as a result. There was also no significant difference in average number of shots per rally between trials (for all rallies and for winning or losing rallies), and no significant difference in unforced errors for whole match or by set. This indicates that participants played a similar number of points and had a similar number of rallies during both the placebo and CHO-E trials.

Gillet et al. (2009) stated that serves and serve-returns are the two strokes that have the greatest influence on match results in modern tennis games, therefore serving a higher percentage of serves into the court and returning more serves during the second set of a match should theoretically translate into more points won. In addition, on average 50% of the shots played during each point in this study were a serve or return. However players did not win significantly more points when serving or returning during the CHO-E trial than during the placebo trial during this study, even though serve and return success percentages were found to increase with ingestion of CHO-E. In a tennis match, the serve and return are the two shots which a player has the most time to think about prior to hitting. Therefore, if CHO-E ingestion can help to improve CNS and cognitive activity (Chambers et al., 2009), then these shots could potentially benefit the most. They are also less likely to be influenced by the numerous external factors that cannot be controlled during a tennis match and will vary substantially between subjects, for example players' movement to the ball and tactical decisions. These external factors will subsequently make every shot in tennis different, and therefore any effect of CHO-E ingestion would have to be very large to have a significant effect on rally balls for such a small subject number. These external factors may therefore provide an explanation for the present study finding significant results for the serve and return strokes but no the groundstrokes.

It is also possible that the relatively small number of participants taking part in the trial meant that any benefit of the CHO-E translating into points won was too small to be significant. In practise, if players are getting a small number of extra serves and returns into the court, then it is likely that they would then win only a percentage of those points. Therefore the number of extra points won (if any) was probably too small to make a significant difference to results. Again there has been no previous research into serve and return success rates and points won as a result, following ingestion of a CHO-E beverage.

Mean heart rate values observed during the 2 hour matches of 129 beats/min during the placebo trial, and 132 beats/min for the CHO-E trial were slightly lower than results recorded from other studies that have reported mean heart rate values of 136 beats/min to 161 beats/min during tennis match play (Bergeron et al., 1991; Fernandez et al., 2005; Fernandez-Fernandez et al., 2007; Ferrauti et al., 2001a; Hornery et al., 2007a; Kindermann et al., 1981; Morante & Brotherhood, 2007; Novas et al., 2003; Seliger et al., 1973; Smekal et al., 2001). However, it should be noted that some of the previous values were taken from matches in a real competition situation, where there could be more pressure on the players to win, and which may subsequently have an effect on heart rate. In addition, dehydration has been found to elevate heart rate. Participants used in previous research who were found to have average higher heart rates during tennis match play may therefore have experienced some degree of dehydration, for example Hornery et al., 2007a (Noakes, 1993). Even so, it is worth noting that as previous research has only found a beneficial effect of CHO-E ingestion on skill performance when the players have been fatigued, the findings of this study may have been even more pronounced if players had worked harder during their matches, or if the matches had lasted longer than 2 hours.

Accelerometer data found that our participants spent significantly less time doing low intensity activity, and more time in a moderate intensity activity zone during the CHO-E trial (using intensity activity zones as defined by Ekelund et al., 2005). This result coincides with the finding that subjects felt higher levels of activation one hour into the match, therefore even though no conclusions are able to be drawn from these findings they do seem to concur. Heart rate data showed a similar pattern of intensity zones to the accelerometer data; however no significant difference was identified. This finding could therefore indicate that for sports like tennis, an accelerometer may be a more sensitive measure of intensity than heart rate monitoring alone and should be investigated further, as no previous literature was found to give details of movement intensity values for elite level tennis players.

It is important to emphasise for both players and coaches that during a match players will hit the ball an average of 2-3 times per point (Deutsch et al., 1998), which means that serve and return shots comprise 33-50% of total shots played during each point. If a CHO-E drink can help to improve even a small proportion of these two shots, then this could potentially make a large contribution to a player's total game. In addition, if players feel higher levels of activation and are moving with higher levels of intensity through ingestion of carbohydrate during a match, then these are again important findings to consider.

Limitations of the study

There are a few limitations identified for the present study. Firstly, only the subjects were requested to complete a food and physical activity diary so that levels of energy, fluid and physical activity conditions were as similar as possible for both trials. The opponents were therefore only monitored in terms of heart rate to check that their intensity levels were similar for both trials, but not in terms of fluid, energy or physical activity prior to or during the trials. This lack of monitoring of the opponent may have reduced the reliability of the study.

Secondly, over ninety percent of the participants were right-handed players, which may have had an impact on the results showing performance improvements to one side of the court only. In addition, as the player and opponent had to play each other twice (once during each of the two trial), all participants would have had a preconception coming into the second match as to how they would be able to compete. Unfortunately there is no reliable way to measure how any preconceptions may have impacted on performance during the second trial.

Finally, accelerometry data were collected using 15 second intervals, whilst heart rate data were collected using 60 second intervals. As a result, the difference between active and passive behaviour on court is less sensitive using the heart rate monitors, which may provide an explanation for the lack of any significant result for the heart rate data. Any future research into tennis performance would benefit from using smaller intervals to record heart rate data, as the intermittent nature of tennis is not accurately reported using intervals of 60 seconds.

Further Research

For future research, it would be useful to further investigate the impact of CHO-E drink ingestion on serve success rates during the match, in particular looking at the leg drive and ball toss height / contact point of serve throughout a longer match, where overall serve success and 1st serve success are both likely to decline. It would also be interesting to find out why this is the third study to find that serve to the advantage side is affected more by fatigue than serve to the deuce side. As the majority of the participants in this study were right handed players, it would be good to exmine the influence of fatigue on serve to the deuce and advantage side for right and left handed players separately. In addition, it would be beneficial to focus on the wide serve when looking at velocity. On the return of serve, it would be valuable to examine both reaction time and contact point in relation to the body, and to explore the mechanisms behind the increase in return of serve success with CHO-E drink ingestion. In addition, it would be useful to further investigate the use of accelerometers as a measure of intensity levels in tennis. All of these could be studied using notational analysis in matches lasting a longer duration (up to 5 hours to induce greater fatigue) or in tournament play (where two matches are played in a single day and where an impact may be noticed more clearly in the 2nd match).

It is still unclear from the findings of this study whether carbohydrate ingestion can improve performance by reducing a detrimental change in serve and return kinematics with increased physiological strain, or whether perceptual-cognitive functioning is the main source of improvement. It is also unclear whether the improvements in tennis performance were the result of oral sensing or the central effects of CHO-E ingestion. Future research on carbohydrate and skill performance in tennis therefore needs to adopt a holistic approach to performance, attempting to encapsulate physiological, biomechanical and perceptual-cognitive information simultaneously, with a focus on serve and return.

It is interesting that the skill test did not produce any findings, as the majority of previous research has focused on skill testing as a methodology. The current study indicates that real match play situations should be adopted for future research, and in particular the central activation / psychological effects of CHO-E ingestion should be examined. By investigating these areas further, a more complete conclusion could be drawn in terms of exactly how CHO-E drink ingestion is contributing to both mental and physical performance.

Conclusions

The findings from this study are different to previous investigations in that skill test results indicate that participants were not fatigued by the testing procedures, however carbohydrate supplementation was still found to have a beneficial effect on the performance of some shots. Previous research has found carbohydrate ingestion to be effective only when participants have been pushed to volitional fatigue or following activity that is physiologically more strenuous than is usually observed under normal match play conditions. Methodological oversights therefore challenge the relevance of findings from the majority of previous research into carbohydrate ingestion and tennis performance, owing largely to the fact that the demands of actual match play are extremely difficult to replicate in a scientific field-based experiment that places a large emphasis on control, standardisation and reliability. Unfortunately, data collected under real tournament conditions is currently very limited, and findings have been ambiguous.

Overall the hypothesis was supported, as data indicate that CHO-E drink ingestion during a tennis match can contribute towards maintaining performance by increasing overall percentage of successful serves and increasing return success rates. In particular, first serves and serves to the advantage side, as well as return success rates during the second set of a match were found to significantly improve with carbohydrate ingestion. These changes may be linked to increased perceived activation, and increased intensity of movement sustained on court in the CHO-E trial. However, the improvements in serve and return success rates are not associated with player ability or glucose elevation, and it is unclear whether these changes are related to the central effects of CHO-E ingestion, therefore further research is needed to explore the potential mechanisms behind these improvements.

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Websites

The International Tennis Federation: www.itftennis.com

CONSENT FORM

CONSENT BY PATIENT/VOLUNTEER TO PARTICIPATE IN:
A Postgraduate Research Study

Name of Patient/Volunteer:

…..

Name of Study: Carbohydrate Ingestion and Skill Performance in Tennis

Principal Investigator: Kirsty McRae

I have read the patient/volunteer information sheet on the above study and have had the opportunity to discuss the details with the principal investigator, Kirsty McRae, and ask questions. She has explained to me the nature and purpose of the tests to be undertaken. I understand fully what is proposed to be done.

I have agreed to take part in the study as it has been outlined to me, but I understand that I am completely free to withdraw from the study or any part of the study at any time I wish. I understand and agree that my participation in the study is entirely at my own risk.

I understand that these trials are part of a research project designed to promote medical or scientific knowledge, which has been approved by the Sports Studies Ethics Committee, and may be of no benefit to me personally. The Sports Studies Ethics Committee may wish to inspect the data collected at any time as part of its monitoring activities.

I also understand that my General Practitioner may be informed that I have taken part in this study if any unusual or surprising observations are made.

I hereby fully and freely consent to participate in the study which has been fully explained to me.

Signature of Patient/Volunteer:

.. Date: ……………..

I confirm that I have explained to the patient/volunteer named above, the nature and purpose of the tests to be undertaken.

Signature of Investigator:

.. Date: …………….

Appendix 2

UNIVERSITY OF STIRLING

DEPARTMENT OF SPORTS STUDIES

Date	Physiologist	Signature

Pre-Participation Health Screen Questionnaire (PPHS-Q)

PPHS-Q is an exercise – specific checklist for classification of training categories.
Accuracy in completion of the PPHS-Q is of the utmost importance

The purpose of the Fitness Centre (FC) pre-participation health screen is:

- To optimise safety during exercise testing and programme description.
- To identify medical risk factors which may contra-indicate exercise.
- To identify those with special needs.

Name:____________________________________Age:______________ FC no______________

Address____ Gender:______________

____Tel:_______________(H) ______________(W)

Doctor's name:__________________________________Tel:_______________(H)______________(W)

Section A: Medical History Summary and Recommendations	
Date:	
Date:	
Date:	

	Section B: Coronary Heart Disease Risk Index	**Date**	**Date**	**Date**
1. 1-10	No supervision required – exercise at will			
2. 10-17	No supervision required – use general exercise guidelines			
3. 18-27	No supervision required – use prescribed programme only			
4. 28-40	Use prescribed programme – Personal Training recommended			
5. 41+	Use prescribed programme – Personal Training and re-test within 8 weeks recommended			

Section C: Physical Activity Index					
		Date:			
Activity Level	**Times per week**	**Risk level**			
Inactive	0 occasional	Very High			
Semi-active	1	High			
Active	2-3	Moderate			

Very active	4 or more	Low			

SECTION A **MEDICAL HISTORY**

Have you ever been told that you have had or have any of the following conditions? If yes, please mark with an X in the appropriate box:

CARDIAC (Heart Related Diseases)

o Heart Attack
o Coronary thrombosis (blood clot)
o Narrowing of arteries
o High cholesterol
o High blood pressure
o Rheumatic fever
o Angina / Chest Pain
o Congenital Heart Disease

o Further / comments

PULMONARY (Lung Diseases)

o Asthma
o Chronic Bronchitis
o T.B.
o
o Exercise-induced asthma
o Emphysema

o Other / comments

OTHER

o Type I Diabetes (insulin dependent)
o Anaemia (ion deficiency)
o Kidney disease
o Rheumatoid Arthritis
o Type II Diabetes (non-insulin dependent)
o Rheumatic fever
o Angina / Chest Pain
o Congenital Heart Disease
o Pregnant

o Other / comments

ORTHOPAEDIC SURGERY (Musculo Skeletal)

Surgery

o Neck
o Back
o Shoulder
o Arm
o Hip
o Knee
o Ankle
o Foot

o Other / comments

INJURY

Have you suffered any of the following injuries? If so, how long ago?

o Neck vertebrae
o Rotator cuff
o Tennis elbow
o ITB
o Achillies Tendonitis
o Back vertebrae
o Impingement Syndrome (shoulder)
o Runner's knee
o Lower leg
o Plantar Fascitis

o Other / comments

MEDICATION

Do you use medication at present for any of the following? (If yes, please state the drug)

o Heart rhythm
o Blood pressure

o	Blood clotting.	o	Blood circulation
o	Asthma	o	Bronchitis
o	Emphysema	o	Flu
o	Diabetes	o	Thyoid dysfunction
o	Cholesterol	o	Anaemia
o	Kidney	o	Liver
o	Arthritis	o	Muscle injury
o	Other / comments		

SECTION B **CARDIOVASCULAR DISEASE RISK INDEX**

Please read the following questions carefully and answer each accurately. Mark your choice with an X.

History of heart attack or bypass surgery / angioplasty

0	o	None	5	o	1 – 2 years ago
2	o	Over 5 years ago	8	o	< 1 year ago
4	o	3 – 5 years ago			

Family history of heart disease

1	o	No known history
2	o	1 relative with cardiovascular disease over the age of 60
3	o	2 relatives with cardiovascular disease over the age of 60
4	o	1 relative with cardiovascular disease under the age of 60
6	o	2 relatives with cardiovascular under the age of 60
8	o	Heart – related sudden death:
	o	Male, first degree relative before the age of 55
	o	Female, first degree relative before the age of 65

Age / Gender Index

0	o	Male / female under 30 years of age
1	o	30 – 40 years of age
2	o	Female 40 - 50 years of age
3	o	Male 40 – 50 years of age
3	o	Female 50 – 60 years of age
4	o	Male 50 – 60 years of age
4	o	Male / female 60+ years of age

Smoking status

0	o	None
1	o	Pipe
2	o	1 – 10 cigarettes daily
3	o	11 – 20 cigarettes daily
4	o	21 – 30 cigarettes daily
5	o	31 – 40 cigarettes daily
6	o	41 – 60 cigarettes daily
8	o	+ 60 cigarettes daily

State how long you have smoked for:
Years_______________months_____________

How would you describe your bodyweight?

0	o	Ideal weight
2	o	0 – 5kg overweight
4	o	6 – 10kg overweight
6	o	11 – 15kg overweight
8	o	+ 15kg overweight
10	o	Underweight

Total Cholesterol

0	o	< 5 mmol / L
1	o	5.0 – 5.2 mmol / L
3	o	5.3 – 5.9 mmol / L
5	o	6.0 – 6.2 mmol / L
6	o	6.3 – 6.9 mmol / L
7	o	7.0 – 7.5 mmol / L
8	o	> 7.5 mmol / L
	o	Not sure

Systolic Blood Pressure			**Diastolic Blood Pressure**		
0	o	< 130 mmHg	0	o	< 80 mmHg
1	o	130 – 140 mmHg	1	o	81-90 mmHg
2	o	141 – 150 mmHg	2	o	91 – 100 mmHg
3	o	151- 160 mmHg	3	o	101 – 110 mmHg
4	o	> 160 mmHg	4	o	> 110 mmHg
	o	Not sure		o	Not sure

Diabetes			**Occupational activity level**		
0	o	None	1	o	Intense physical labour
1	o	Type 11 (non-insulin dependent)	2	o	Moderate (walk often etc.)
2	o	Type 1 (insulin dependent)	3	o	Sedentary

Work Stress Tension		
0	o	No stress, very relaxed
1	o	Moderate work stress and relaxed personality
2	o	High work stress but cope well
3	o	Very high work stress and tense personality
4	o	Very high work stress, highly strung personality

Physical Activity Status (for a minimum of 30 minutes a session)		
1	o	Exercise 4 or more times per week
2	o	Exercise 2 – 3 times per week
3	o	Recreational sport once a week
4	o	Recreational sport occasionally or complete lack of exercise

SECTION C **EXERCISE PARTICIPATION**

Do you participate in any of the activities more than twice weekly?
(Please tick all relevant activities)

o	Jogging more than 5 km	o	Aerobic classes 45 min
o	Cycling more than 45 min.	o	Tennis 90 min
o	Swimming more than 600 m	o	Squash 45 min.
o	Gym (Combined strength / aerobic)	o	Team sport (outdoor) – rugby hockey, soccer
o	Gym (weights only)	o	Team sport (indoor) – basketball, netball, etc
o	Gym (aerobic only)	o	Canoeing / Rowing 45 min

SECTION D

I have read, understood and completed this questionnaire to the best of my knowledge.
I am aware of the risk involved in fitness testing and understand the test procedures that I will perform. I give consent to participate in this assessment.

TEST 1

Date:______________________________

SIGNATURE:______________________________ WITNESS:__________________________
(for a minor)

SIGNATURE OF PARENT:__________________________

TEST 2

SIGNATURE:____

Date:__________________________________

SIGNATURE OF PARENT:_____________________________

WITNESS:______________________________
(for a minor)

TEST 3

SIGNATURE:____

Date:__________________________________

SIGNATURE OF PARENT:_____________________________

WITNESS:______________________________
(for a minor)

PHOTOGRAPHY AND FILMING: CONSENT FORM

I give permission for me/my child_______________________________________

to be involved in any publicity (including photographs/presentations etc.) surrounding the following experimental trial: **Carbohydrate Ingestion and Skill Performance in Tennis**

Signed		Date	
Name (please print)			
Address			

Full details of Parent/Guardian if under the age of 18.

Name: (please print)		
Address: (If different from above)		
Contact Numbers:	Mobile:	
	Home:	
	Work:	
Email Address:		
Signed:		

Please return this form to:

Name (please print):	Kirsty McRae
Address:	38 Majors Loan Falkirk FK1 5QA

FEELING SCALE (pleasure-displeasure)

While participating in exercise is it quite common to experience changes in mood. Feelings may fluctuate across time so you might feel good then bad a number of times during exercise.

Using the feeling scale below please rate how you would say you generally feel right now.

Circle your response below

-5	-4	-3	-2	-1	0	+1	+2	+3	+4	+5
very bad		bad		fairly bad	neutral	fairly good		good		very good

FELT AROUSAL SCALE (perceived activation)

While exercising it is also common to feel changes in your state of arousal / activation.

Using the scale below please rate how you feel right now.

Circle your response below

1	2	3	4	5	6
low arousal / activation					high arousal / activation

AD ACL Short Form

Instructions

Each of the words on the sheet below describes feelings or mood. Please use the rating scale next to each word to describe your feelings *at this moment*.

EXAMPLES:

Relaxed:	vv	v	?	no	If you circle the double check (vv) it means that you *definitely feel* relaxed *at the moment*
Relaxed:	vv	v	?	no	If you circle the single check (v) it means that you feel *slightly* relaxed *at the moment*
Relaxed:	vv	v	?	no	If you circle the question mark (?) it means that the word does not apply or you cannot decide if you feel relaxed *at the moment*
Relaxed:	vv	v	?	no	If you circle the no (no) it means that you are *definitely not* relaxed *at the moment*

Checklist

Work rapidly, but please mark all the words. Your first reaction is best. This should take only a minute or two.

vv	v	?	no	:	Definitely feel
vv	v	?	no	:	Feel slightly
vv	v	?	no	:	Cannot decide
vv	v	?	no	:	Definitely do not feel

Active:	vv	v	?	no	**Drowsy:**	vv	v	?	no
Placid:	vv	v	?	no	**Fearful:**	vv	v	?	no
Sleepy:	vv	v	?	no	**Lively:**	vv	v	?	no
Jittery:	vv	v	?	no	**Still:**	vv	v	?	no
Energetic:	vv	v	?	no	**Wide-awake:**	vv	v	?	no
Intense:	vv	v	?	no	**Clutched-up:**	vv	v	?	no
Calm:	vv	v	?	no	**Quiet:**	vv	v	?	no
Tired:	vv	v	?	no	**Full-of-pep:**	vv	v	?	no
Vigorous:	vv	v	?	no	**Tense:**	vv	v	?	no
At-rest:	vv	v	?	no	**Wakeful:**	vv	v	?	no

Dnamic Warm-up for CHO and Skill Performance in Tennis testing

Exercise	Distance / Time
1. Jogging lap of court 5	2 laps
2. Side steps facing net with arm swings above head	2 court widths
3. Cross-overs facing the net	2 court widths
4. Cross-overs facing the net with high knee	2 court widths
5. High knees forwards	1 court width
6. High knees backwards	1 court width
7. Heel flicks forwards	1 court width
8. Heel flicks backwards	1 court width
9. Straight lunges forwards	1 court width
10. Straight lunges backwards	1 court width
11. Open the gait forwards (hip adductors)	1 court width
12. Close the gait forwards (hip abductors)	1 court width
13. Hamstring kicks forwards	1 court width
14. Pirouette superman with arms above head	1 court width
15. Bound and hold	1 court width
16. Heel to toe walks	1 court width
17. Bodyweight squats	x10
18. Keyhole slaps	x10

5 Minute Racket Warm-up: Groundstrokes only (from the service line, gradually moving back to the baseline)

Borg Rating of Perceived Exertion (RPE) Scale

Exertion	**RPE**
No exertion at all	6
Extremely light	7
	8
Very light	9
	10
Light	11
	12
Somewhat hard	13
	14
Hard (heavy)	15
	16
Very hard	17
	18
Extremely hard	19
Maximal exertion	20